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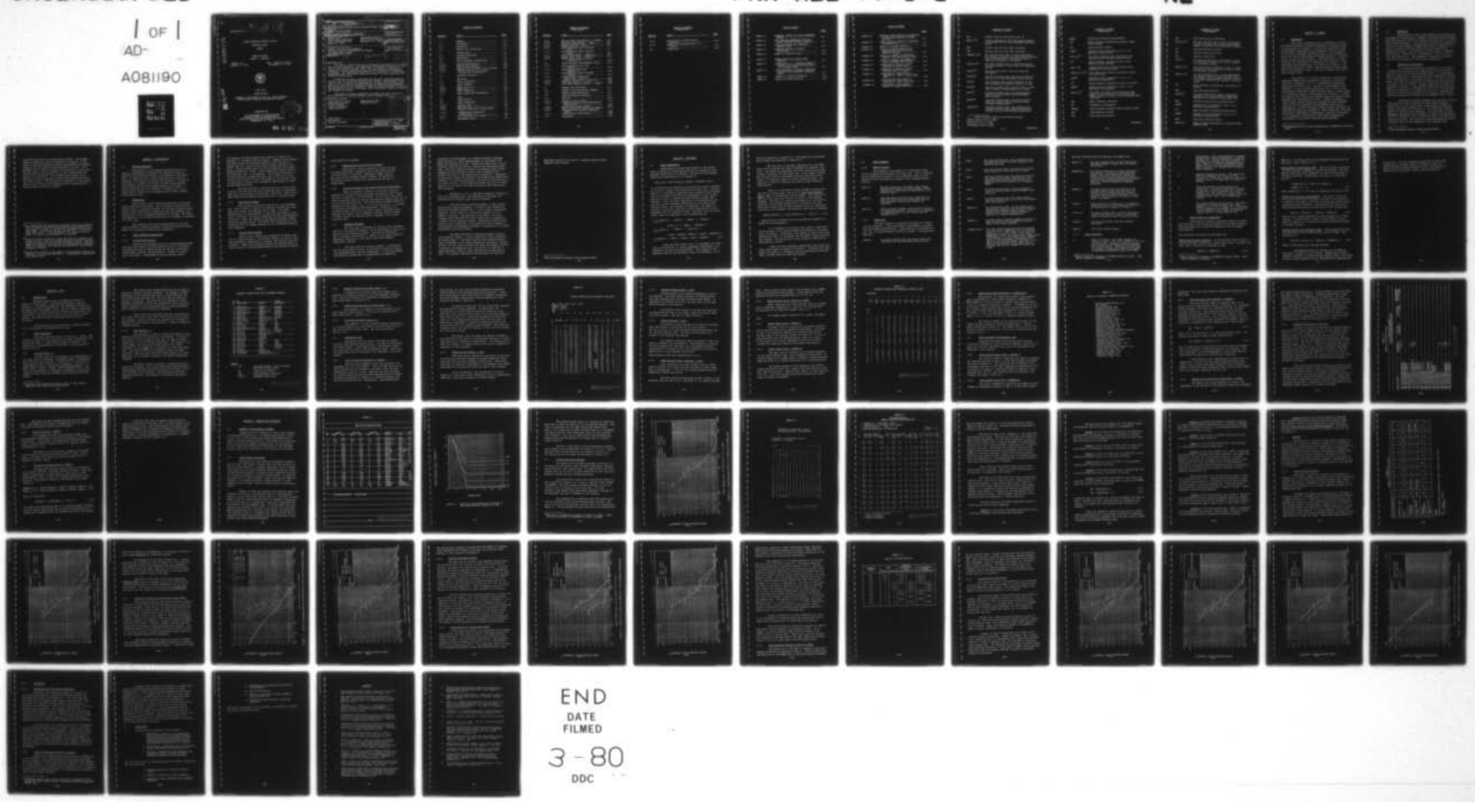

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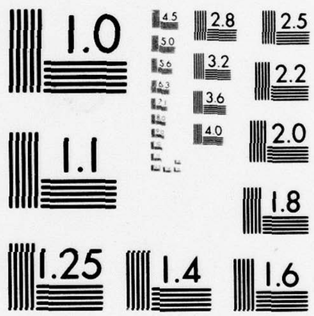

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LEVEL II

NOISE ABATEMENT ECONOMIC POLICY

ANALYSIS MODEL

NAEPAM

ANDRAS SPIEGEL
ROGER A. SHEPHERD

KETRON, INC.
WAYNE, PA 19087

CSC - INFONET DIVISION
ARLINGTON, VA 22209

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FINAL REPORT

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KETRON, INC.
PHILADELPHIA OPERATIONS
530 E. SWEDESFORD ROAD
WAYNE, PA 19087

CSC-INFONET DIVISION
1616 N. FORT MEYER DR.
ARLINGTON, VA 22209

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16. Abstract (Limit: 200 words)

This report examines the role of economic disincentive as an inducement to noise abatement. The particular disincentive analyzed is a system of noise emission charges (NEC) which is imposed at airports on commercial aircraft operations which are above maximum noise emission allowances. The methodology developed is in the form of a mathematical programming (MP) model which seeks to minimize the total cost of a disincentive-based policy.

Preliminary analyses conducted with the model indicate (qualitatively) that the method of noise emission charges, administered at the airport level on operations exceeding the current noise emission standards, is an economically feasible method for inducing noise abatement. The single most critical assumption underlying this conclusion is that if the NEC administration is voluntary, then a sufficient number of airports must impose the charges.

The modeling concept presented is suitable for the analysis of a broad spectrum of aviation economic policy related issues.

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GLOSSARY OF TERMS

AAS	Airport Activity Statistics, Ref. 10
BAS(k,t)[2/]	Varying component of the fleet which consists of airplanes without noise abatement modifications.
BLH	Balance rows for Have (HAV) variables.
BLM	Balance rows for Base (BAS) variables.
CHANGE(k,t)[1/]	For each aircraft type, in each time period, the changes in fleet size (among modified planes) due to considerations outside the scope of decisions available to the model.
CHGB(k,t)[1/]	For each aircraft type, in each time period, the known changes in fleet size for unmodified planes.
CINF(t)[1/]	For each time period, the cost inflation multiplier.
CLAM(k)[1/]	For each aircraft type, the cost of labor and materials for noise abatement modifications.
CO(k)[1/]	The increased cost of each operation if the noise abatement engineering changes are made.
CT(k)[1/]	For each aircraft type, the unit cost of time that a plane is out of service for rework.
EL(k)[1/]	For each aircraft type, the noise emission level of aircraft having noise abatement modifications.
ELB(k)[1/]	For each aircraft type, the noise emission level of aircraft that do not have noise abatement modifications.
ELSTD(k)[1/]	For each aircraft type, the emission-level standard against which escess emissions are charged the unit noise emission surcharge.

These footnotes apply to the entire Glossary.

[1/] Data element used in model.

[2/] Variable used in model.

[3/] Parameter used in model.

Continued..

EPNdB	Effective Perceived Noise Decibels
g 3/	Model parameter representing resource competition groups.
GNP	Gross National Product
GUSE 1/	Maximum value of parameter g (q.v.) in a particular optimization.
HAV(k,t) 2/	The active planes in the fleet which have undergone noise abatement modifications.
i 3/	Model parameter representing unit noise emission charge options.
ICAO, CAN	International Civil Aviation Organization, Committee on Aircraft Noise.
IGROUP(g+1,k) 1/	Data element for resource contention indicators and values.
IUSE 1/	Maximum value of parameter i (q.v.) in a particular optimization.
k 3/	Model parameter representing type of aircraft.
KUSE 1/	Maximum value of parameter k (q.v.) in a particular optimization.
MAK(k,t) 2/	The number of "make" activities which take place in a time period on an aircraft type. "Make" refers to rework or noise abatement modifications.
MGG	Matrix Generator Generator
MP	Mathematical Programming
NAEPAM	Noise Abatement Economic Policy Analysis Model
NEC	Noise Emission Charges
NEF	Noise Emission Forecast

Continued..

GLOSSARY OF TERMS
(Continued)

NSC	Noise Sensitivity Coefficient
OP(k,t,s)[1/]	For each aircraft type, in each time period, at each size class of airport, the average number of operations per aircraft per period.
POA	Post-Optimization Analysis
RCG	Resource Competition Group
RNL	Residual Noise Level
RW(k)[1/]	For each aircraft type, the number of units of time that a plane will be out of service if it undergoes rework.
RWGB(g,t)[1/]	For each resource competition group, in each time period, the availability limit on units of the scarce resource.
RWUB(k,t)[1/]	For each aircraft type, in each time period, the greatest number of such aircraft which can undergo noise abatement modifications due to aircraft modification industrial capacity limits.
s[3/]	Model parameter representing 'size-class' of airport.
SAM	Sound Absorbing Material
SIZE(s)[1/]	For each airport size class, a multiplier applied to the noise emission charges for operations at airports of that size class.
SMSA	Standard Metropolitan Statistical Area
SUSE[1/]	Maximum value of parameter s (q.v.) in a particular optimization.
t[3/]	Model parameter representing time period.
TUSE[1/]	Maximum value of parameter t (q.v.) in a particular optimization.
UNEC	Unit Noise Emission Charge
UNEC(i)[1/]	Model variable representing an array of data; defined above.

SECTION 1. SUMMARY

1.1 BACKGROUND

The initial introduction of jet commercial aircraft was shortly followed by sporadic complaints of excessive noise in the proximity of airports. This was not surprising, since jet propulsion represented a new technology, not all aspects of which were thoroughly understood prior to its introduction. One of the least studied aspects included acoustics -- external noise, its sources and abatement. The combination of events following the introduction of commercial jet aircraft -- their acceptance and proliferation, the location of airports in (or near) urban population centers, and the growth of public awareness of environmental issues -- has led to demands for relief from aviation noise.

The histories of aircraft propulsion oriented noise abatement research and of regulatory activities are briefly outlined in references (1,2,3). A comprehensive regulatory review may be found in (11). The U.S. noise abatement rules currently in force are FAR-36 and FAR-91 (4,5), while on the international scene ICAO's CAN[1/] has been active. A more recent U.S. regulatory attempt is represented by H.R.8729(6). Studies of aviation noise relief using methods other than aircraft noise abatement are illustrated by (7,8,9). Methods considered in these studies include operational changes for noise abatement (such as the $6^{\circ}/3^{\circ}$ approach, now considered operationally unacceptable), as well as relief through acoustic insulation of dwellings and land use alterations. These references, while far from being a comprehensive bibliography, provide an indication of the technical, institutional, and economic complexities encountered in the realm of aviation noise abatement.

[1/] International Civil Aviation Organization, Committee on Aircraft Noise

1.2 OBJECTIVES

The objectives of the study reported here address only one aspect of the economics of commercial aviation noise abatement. This study examines the role of economic disincentive as an inducement to noise abatement. The particular disincentive analyzed is a system of noise emission charges (NEC) which is imposed at airports on aircraft operations which are above maximum noise emission allowances. The feasibility of this method is examined qualitatively. Specifically, a methodology -- which is one of the study objectives -- was developed for setting the disincentive level and assessing its potential consequences.

1.3 RESULTS AND CONCLUSIONS

The resulting methodology developed is in the form of a mathematical programming (MP) model which seeks to minimize the total cost of a disincentive-based policy. The optimization model is supported by a post-processor which displays the effects of the selected NEC at the optimal solution. The details of the model, the underlying assumptions and restrictions are described in Section 3 of this report. The data supporting the model are described in Section 4. Some detailed results and further applications of the model are discussed in Section 5. The mechanization of the model and instructions for its use in implementing additional analyses are provided in the "NAEPAM[1/] User's Guide."

Preliminary analyses conducted with the model indicate (qualitatively) that the method of noise emission charges, administered at the airport level on operations exceeding the current noise emission standards, is an economically feasible method for inducing noise abatement. The single most critical assumption underlying this conclusion is that if the NEC administration is voluntary, then a sufficient number of airports must impose the charges. The analytical results presented in Section 5 indicate that the set comprised of all large-hub class

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[1/] Noise Abatement Economic Policy Analysis Model

airports[1] would meet the sufficiency criterion. The primary economic feasibility criterion employed is a measure of the impact of the noise emission charges on passengers and shippers, assuming that all charges would be passed on to them. It is estimated that a uniform increase of 0.44 percent in fares and freight charges, over a period of 13 years, would defray the costs of the program.[2] This increase would result in an expected 88 percent decrease in excess noise emissions[3] below the current levels. The quantitative assessment of the economic impact of any noise emission charge would be accomplished by a detailed demand elasticity analysis.

1/ Air traffic hubs are defined by the Airport Activity Statistics (10) as Standard Metropolitan Statistical Areas (SMSAs) where 0.05 percent (or more) of the national enplanements take place. Large hubs: 1 percent or greater, medium hubs: 0.25-.99 percent, small hubs: 0.05-0.24 percent. Air carrier airports below 0.05 percent of enplanements are non-hubs.

2/ It will be shown in Section 5 that this value is slightly optimistic in that it does not include the cost of capital required during the early part of the noise abatement program. The error bound is, however, established by the "pay-as-you-go" schedule. Under this schedule, the cash flow is provided by time-variable increase in tariffs.

3/ Excess noise emission, with respect to the standard used for the analysis -- in this case FAR-36(4) -- arithmetically accumulated on a yearly basis.

SECTION 2. INTRODUCTION

2.1 PROGRAM OBJECTIVES

The objective of the program reported herein is to develop a methodology to establish the appropriate level of effective noise emission charges, to be imposed at the airport level, on operations which violate specified noise emission standards. The objective sought by the program is a system of noise emission charges which induce aircraft noise abatement modifications and which are deemed economically feasible. A desired characteristic of the system of charges is that the charge should increase with increasing excess (above standard) noise emission level.

2.2 METHODOLOGY

The statement of the objectives implicitly directs the general method of the program. Since increasing noise emission levels result in increasing charges, and the noise emission charge may be avoided completely by compliance with the standards, the problem falls into the economic disincentive category. The standard response to any economic disincentive is to attempt to minimize its total value.

The following very brief recapitulation of aviation noise abatement alternatives serves to place the detailed development of the disincentive method into perspective.

2.3 NOISE ABATEMENT ALTERNATIVES

2.3.1 Aircraft Modification

Aircraft noise abatement refers to those permanent modifications which reduce the noise emission levels at the source. The principal areas of modifications are the fan, the exhaust nozzle/thrust reverser, and the nacelle. Changes to the fan are of two types -- replacement of the fan section (refan)

and changing the engine bypass ratio (which is a form of re-*engining*), or insulating the fan section. Exhaust nozzle changes are made to alter the turbulent mixing of high velocity jet exhaust with air, which is one of the principal sources of jet noise. Nacelle changes take the form of insulation using Sound Absorbing Materials -- SAM. A more substantial change, still in the propulsion area, is re-engining. This change is subject to the most stringent economic scrutiny, and is used only in conjunction with aircraft service life extension, particularly when it concurrently promises fuel consumption improvements or other desired operating gains.

The most significant characteristics of aircraft modifications are that they are quite costly and they are permanent -- their use is not subject to the pilots' discretion. None of the above modifications address the problems due to airframe noise.

2.3.2 Operational Changes

The principal operational changes for noise abatement are: power cutback on take-off, flight path alternatives, modified glide slopes, and modified use of flaps. The common characteristic of these methods is that they are subject to the pilots' discretion, and may be neglected if safety considerations so dictate. Their use depends on the density altitude, temperature and aircraft weight. The glide slope modification to the so-called $6^{\circ}/3^{\circ}$ two segment approach is not considered operationally acceptable.

2.3.3 Service Level Changes

Service level changes may be employed to achieve some level of noise abatement. The possible changes are service frequency reduction, application of curfews, and aircraft type substitution. These noise abatement methods are administrative in nature and are of limited effectiveness unless severe disruption

of air service is accepted.

2.3.4 Compensation for Social Cost of Noise

This method is purely punitive in nature and does not offer substantial, permanent relief from aviation noise in the proximity of airports. Rigorously viewed, this is not even a noise abatement method; however, its potential for economic impact warrants its inclusion for the sake of completeness.

2.3.5 Land Use Alteration and Sound Insulation of Buildings

Under this method, oriented to the noise receivers, residential and institutional buildings are suitably sound insulated and, if necessary, air conditioned. In very high noise level areas alternative land use options are exercised, whereby the land is put to noise compatible use. While this noise abatement method is probably the most costly (7,8) -- on a national scale -- it affords a high level of permanence and selectivity. Selectivity is provided through control of the level of sound insulation which controls the results, while permanence protects against changes in fleets, as well as against general, business, and military aviation noise.

2.4 TECHNICAL APPROACH

The five types of methods for aviation noise abatement, which are not mutually exclusive, can be classified as either noise source or noise receiver oriented. The general methodology -- that of economic disincentives -- admits to two types of specific approaches, depending on the class of the noise abatement technique(s) applied.

The noise receiver oriented programs -- compensation for the social cost of noise, or the sound insulation of buildings (complemented by land use alterations) -- pose the problems of finding the lowest cost of accomplishing the objective,

followed by the development of a charge assessment technique which results in a "fair" apportionment of that lowest cost among the producers of noise. Finding the lowest cost, in this instance, poses social science, economic and engineering problems. The social science problem is to determine what is fair compensation for exposure to noise, and to determine who "causes" the noise -- who should pay the penalties. Candidates for penalties include the carriers, the airframe and engine manufacturers, the airport proprietors, the users of the services, or the entire society. The engineering problem would be the determination of the lowest cost sound insulation which meets specified standards.

References (7, 8, 9) represent attempts at evaluating, from various perspectives, the technology and economics of providing relief through noise receiver programs.

The noise source oriented programs -- when aircraft modification, operating changes, or service level changes are the noise abatement methods used -- in an economic disincentive framework, do not result in a fixed cost program, but in a "gaming" situation. The objective of the game is to find a strategy which minimizes the total program cost in response to a system of noise emission charges. The gaming situation which arises in this formulation of the problem is quite amenable to the mathematical programming treatment, in particular to a linear programming optimization model.

The model developed to establish systems of excess noise emission charges -- and to demonstrate their feasibility and effectiveness -- provides aircraft noise abatement modification management as the gaming response by the carrier industry. Section 3 of this report provides the model development, Section 4 describes the supporting data, and Section 5 is devoted to some preliminary results, which indicate how the model may be used. The detailed instructions for executing the model for

additional analyses are given in a separate volume titled, "NAEPAM[1] User's Guide".

[1] Noise Abatement Economic Policy Analysis Model.

SECTION 3. THE MODEL

3.1 MODEL FORMULATION

Noise emission charges administered at the airport level on excessively noisy operations may be avoided by noise abatement modification of aircraft. The value of the economic disincentive established in this manner is:

Total Cost = Noise Emission Charges + Abatement Costs

In a disincentive environment the economically rational response is to act in a manner which minimizes the total cost. The minimization is achieved by performing noise abatement modifications only to the extent that they are advantageous in view of their cost and in view of prospective Noise Emission Charge (NEC) accruals. Thus, the major components of the minimization are: the cost of noise abatement modifications, the excess noise emission levels, the frequency of operations, the number of aircraft in the fleet, the rate at which modifications can be performed, and the schedule of NECs. The total cost to be minimized, given the components, can be represented by:

$$\sum_k \sum_t \sum_s \mathrm{BAS}(k,t) * \mathrm{CINF}(t) * \mathrm{UNEC}(i) * \mathrm{SIZE}(s) * \mathrm{OP}(k,t,s) * (\mathrm{ELB}(k) - \mathrm{ELSTD}(k)) +$$

$$\sum_k \sum_t \sum_s \mathrm{HAV}(k,t) * \mathrm{CINF}(t) * \mathrm{OP}(k,t,s) * (\mathrm{CO}(k) + \mathrm{SIZE}(s) * \mathrm{UNEC}(i) * (\mathrm{EL}(k) - \mathrm{ELSTD}(k))) +$$

$$\sum_k \sum_t \mathrm{MAK}(k,t) * \mathrm{CINF}(t) * (\mathrm{RW}(k) * \mathrm{CT}(k) + \mathrm{CLAM}(k)) \qquad (3.1)$$

Since the model shown as Eq. 3.1 represents the total cost to be minimized, in linear programming terminology it is referred to as the objective function. The elements of the objective function are variables, data, and parameters, all of

which are described in Section 3.2. The bounds and constraints for the model are specified in Section 3.3.

The first sum in the model represents the total NECs which will be accrued over time by unabated, but abatable, aircraft. The second sum represents the costs of operating abated aircraft, providing for the events that: noise abated aircraft may not meet emission requirements and that the modification results in recurring changes in aicraft operating costs. The third sum is used for computing the costs of noise abatement modifications.

Since it is desirable to have the NECs increase with the level of excess noise, the notion of Unit Noise Emission Charge (UNEC) is incorporated into the model. The dimension of UNEC is dollars per unit of noise in excess of the standard, \$/ΔEPNdB. The extent of excess noise emission is calculated by ELB-ELSTD, and EL-ELSTD respectively in the first two sums. Since some aircraft may already be quieter than the requirement indicated by the standard, the following restriction is imposed:

$$ELB(k)-ELSTD(k) \geq 0, \quad EL(k)-ELSTD(k) \geq 0 \quad \text{For all } k \qquad (3.2)$$

implying that no benefits will be provided for abatement in excess of the requirements.

It is important to recognize that airport noise sensitivity depends on land use and population densities in the proximity of airports. Accordingly, the concept of Noise Sensitivity Coefficienct (NSC) is introduced into the model, through the SIZE data element. The application of this concept is described in both Sections 4 and 5.

Since the noise abatement modifications take place over time, their costs are subject to inflation. Provisions for introducing the effects of inflation, both on modification costs and NECs, are made using the CINF data element.

3.2 MODEL ELEMENTS

3.2.1 Model Variables

The objective of the model is to find those values of the variables which minimize the total cost. This is achieved by the simultaneous balancing of all trade-offs among all the possible carrier approaches to aircraft noise abatement modifications.

MAK(k,t): The key variables in the model, their values represent the number of noise abatement modifications which take place in time period t, for aircraft type k.

BAS(k,t): These variables represent those components of the fleet which are not noise abated, but for which abatement modification methods are available.

HAV(k,t): These variables represent noise abated aircraft, or unabatable aircraft. Note that it is possible for abated aircraft to emit noise above the standard level.

3.2.2 Model Data

The data necessary to exercise the model fall roughly into two categories: known engineering relationships, and operating environment specifications. These data may be considered as one, two, or three dimensional tables of numbers. The engineering data are:

CLAM(k): For each aircraft type, the cost of labor and materials for noise abatement modifications.

CO(k):	For each aircraft type, the increased cost of each operation after the noise abatement modifications are made.
CT(k):	For each aircraft type, the unit cost of time that a plane is out of service for rework.
RW(k):	For each aircraft type, the number of units of time (matching the units used in CT(k), not necessarily the modeling time period) that a plane will be out of service if it undergoes rework.
EL(k):	For each aircraft type, the noise emission level of aircraft having noise abatement modifications.
ELB(k):	For each aircraft type, the noise emission level of aircraft that do not have noise abatement modifications.
RWUB(k,t):	For each aircraft type, in each time period, the greatest number of such aircraft which can undergo noise abatement modifications. The restriction is due to limited industrial capacity for aircraft modification.
RWGB(g,t):	For each scarce resource competition group, in each time period, the availability limit on units of the scarce resource.
IGROUP(g+1,k):	For each aircraft type there are two entries. The first entry (IGROUP(1,k) for a particular value of k) is a code number n that indicates membership in group g if n=g, or no group membership if n=0. The second entry (IGROUP(2,k)) is the number of units of the scarce resource used by a noise abatement modification to a plane of this aircraft type. Note that it is a part of the structure of the model that an aircraft type may be a member of at most one group.

The data characterizing the operating environment are:

CHGB(k,t): For each aircraft type, in each time period, the known changes in fleet size for unmodified planes.

CHANGE(k,t): For each aircraft type, in each time period, the changes in fleet size (among modified planes) due to considerations outside the scope of decisions available to the model. For instance, contracted purchases for delayed arrival or scheduled retirement programs. Note that CHGB and CHANGE are completely analogous.

ELSTD(k): For each aircraft type, the emission-level standard above which excess emissions are charged the unit noise emission surcharge. Our data used the FAR-36 standards, but any higher or lower standards are equally acceptable to the model.

SIZE(s): Noise sensitivity coefficient. A multiplier applied to the unit noise emission charge (q.v.) for operations at airports of Class s.

OP(k,t,s): For each aircraft type, in each time period, at each size class of airport, the average number of operations per aircraft per period.

CINF(t): For each time period, the cost inflation multiplier.

UNEC(i): Unit Noise Emission Charge.

3.2.3 Model Parameters

k: Type of Aircraft. This model parameter is allowed to take on any value, presently up to and including 40[1/]. Examples of type of aircraft are an L1011-200 or a Boeing 727-200 equipped with JT8D-9 engines. Each such aircraft type is assigned a sequential number for reference to variables and equations within the model.

[1/] These values are analogous to FORTRAN dimension values. They may be changed as necessary.

t: Time Periods. This model parameter is allowed to take on any value, presently up to and including 24[1]. The data currently prepared for the model have treated the time period as a year. There is no modeling requirement which forces the choice of this particular unit of time, as long as all related data are consistently prepared.

g: Resource Competition Groups. This model parameter may presently have values to 5[1]. A group is a collection of aircraft types which require access to a common pool of scarce resources.

s: Class Designation for Noise Sensitivity Coefficient. This model parameter is allowed to take on any value, presently up to and including 9[1]. The airport hub size classes actually used were the small, medium, and large classifications used in the standard data sources.

i: Unit Noise Emission Charge Option. This model parameter is allowed to take on any value, presently up to and including 50[1]. The purpose of this parameter is to submit a variety of surcharge candidates to the model and optimize against each in a single computer run.

3.3 MODEL BOUNDS AND CONSTRAINTS

The objective function is optimized subject to bounds and constraints, which serve as elements of the model structure and which specify the limitations imposed by the environment being modeled.

The constraints and bounds for the model are:

Upper bound for Make variables. If the maximum number of modifications indicated in RWUB(k,t) (rework upper bound) is greater than zero, then a limitation is enforced so that:

$$MAK(k,t) \leq RWUB(k,t) \tag{3.3}$$

---

[1] These values are analogous to FORTRAN dimension values. They may be changed as necessary.

RWUB(k,t) = 0, implies that no noise abatement modification can take place, that is MAK(k,t) ≡ 0.

Scarce Resource Constraints (LIM). There is one such constraint for each occurence of RWGB(g,t) (rework group bound). The constraint limits the total consumption of the scarce resource to the level available. Specifically, for each g, in each time period t,

$$\Sigma \text{ IGROUP}(g+1,k) * \text{MAK}(k,t) \leq \text{RWGB}(g,t)$$
$$\text{IGROUP}(1,k) = g \qquad (3.4)$$

where IGROUP(g+1,k) is the rate of consumption per MAK activity.

Balance rows for Base variables (BLM). The effect of MAK(k,t) is to take a plane from the BAS(k,t) and add it to the HAV(k,t). In addition, the CHGB(k,t) data may indicate some changes due to conditions outside the model. The equations that keep all of this straight from period to period for the BAS variables are:

$$\text{BAS}(k,t) = \text{BAS}(k,t-1) - \text{MAK}(k,t) + \text{CHGB}(k,t) \qquad (3.5)$$

There is one of these equations for each occurence of the base variable. In time period 1, *BAS(k,0) simply fails to occur,* requiring CHGB(k,1) to include any initial allocation of planes to the BAS variables.

Balance rows for Have variables (BLH). These equations perform the same function as the BLM functions just described. The equations are:

$$\text{HAV}(k,t) = \text{HAV}(k,t-1) + \text{MAK}(k,t) + \text{CHANGE}(k,t) \qquad (3.6)$$

There is one equation for each HAV variable.

The implementation and execution of the model is described in Volume II of this report, "NAEPAM User's Guide". Section 4 describes in detail the data elements used in the model, as well as their sources, and any transformations required prior

to their use. The full richness and potential of this model formulation will become evident in Section 5, where the post-optimization analysis method is shown, and through the results of six preliminary studies that are presented.

SECTION 4. DATA

4.1 ORGANIZATION

The data elements used in NAEPAM are defined in Section 3 of this report. This section maintains a parallel structure -- discussing parameters, noise abatement engineering, and operational/environmental data. For the reader's convenience, the definition is repeated, the data sources are identified, and alternatives, with their implications, are discussed if appropriate. Any required steps in data preparation are also described.

The organization of the data into a computer readable file is described in the NAEPAM User's Guide.

4.2 MODEL PARAMETERS

The model parameters serve two functions. Namely, they provide the means for user control of the model's dimensions, and provide the means for establishing analysis scenarios. The properties of the parameters are described in the remainder of this sub-section.

4.2.1 Aircraft Type -- k

Aircraft types may be aggregated (or disaggregated) by the model user, as necessary. The highest level of aggregation may be made by make and model -- such as DC-8.[1/] The level of disaggregation used in the analysis presented in Section 5 is: MAKE- MODEL- SERIES- ENGINE- NOISE ABATEMENT OPTION. This level of disaggregation is employed to adequately discriminate between aircraft that have different noise emission characteristics.

[1/] Possible higher aggregation levels, such as "four engine turbojets" are likely to distort results.

The aircraft type categorization may also be used by analysts to control analysis scenarios. For example, if some percentage of one aircraft type (which is noise abatable) will be retired rather than modified, then the aircraft should be placed in two groups. One group will be available for noise abatement modification within the optimization, while the other group, designated by the appropriate data, is made unabatable, and is retired at the user specified schedule.

The aircraft for which data have been collected are: B707, B720, B727, B737, B747, DC-8, DC-9, DC-10, A-300, L-1011, and CONCORDE. These 11 aircraft are divided into 27 groups to capture all their relevant characteristics. Table 4-1 shows the relevant details.

4.2.2 Time Periods -- t

This parameter is used to control the number of time periods over which the optimization is performed. The unit of time chosen for the analysis is one year, in order to obtain stable data -- free of seasonal fluctuation. The choice of time units impacts the optimization computational cost, which increases with the number of time periods, not with their duration. The units of time do not otherwise impact the model structure. When the time units are changed however, all other data must also be changed to maintain the model's dimensional integrity.

The results shown in Section 5 indicate both eight and 13-year programs. The 13-year period was selected since it approximately represents the end-of-life for the fleet of aircraft included in the analyses. The eight year period was selected arbitrarily, for purposes of displaying the model's behavior.

TABLE 4-1

AIRCRAFT, ENGINES AND NOISE ABATEMENT METHODS

AC NO	AC MAKE/MODEL	ENGINE	NOISE ABATEMENT
1	B737-200	JT8D-7	FCD+QN
2	B737-200/200C	JT8D-9	FCD+QN
3	B737-200	JT8D-15,-17	FCD+QN
4	B727-100C/QC	JT8D-7	FCD+QN
5	B727-200	JT8D-7	FCD+QN
6	B727-200	JT8D-9	FCD+QN
7	B727-200	JT8D-15,-17	FCD+QN
8	B707-100B	JT3D-1,-3,-3B	QN
9	B707-300B/C	JT3D,JT4A	QN
10	B720B	JT3D	QN
11	B747-100	JT9D-3A	SAM
12	B747-100	JT9D-7	SAM
13	B747-200B/C/F/SP	JT9D-7	SAM
14	DC-9-10	JT8D-5,-1	FCD+QN
15	DC-9-30	JT8D-9,-15,-17	FCD+QN
16	DC-9-50	JT8D-15,-17	
17	DC-10-10	CF6-6D1	
18	DC-10-30	CF6-50C	
19	DC-10-40	JT9D-20	
20	DC-8-20	JT3D	SAM
21	DC-8-50	JT3D-3B	SAM
22	DC-8-61	JT3D	CFM-56
23	DC-8-63F	JT3D	CFM-56
24	DC-8-62	JT3D	CFM-56
25	A-300B	CF6-50	
26	L-1011-200	RB.211-524	
27	CONCORDE	OLYMPUS 593/MK 610	

LEGEND:

FCD - 'Fan Case Double', Pratt & Whitney BG-16/BG-19 Engine Kits

QN - Boeing Quiet Nacelle

SAM - Sound Absorbing Materials

CFM-56 - GE/SNECMA Power Plant

4.2.3 Resource Competition Groups (RCG) -- g

A collection of aircraft types which compete for a resource of limited availability, for noise abatement modification. The use of RCGs will be discussed in conjunction with data element RWGB -- Section 4.3.8.

4.2.4 Airport Noise Sensitivity Coefficient -- s

This parameter is employed in the development of the noise emission charge system. Its use will be detailed with data element SIZE -- Section 4.4.4.

4.2.5 Unit Noise Emission Charge -- i

This parameter is used to enable multiple optimization in a single computer run, using various selected values of the unit noise emission charge, UNEC. Its use is discussed in Section 4.4.7.

4.3 ENGINEERING DATA

Engineering data are used in the model to specify aircraft noise abatement modifications. The data may be divided into three classes -- modification costs, performance results (as noise emission levels), and modification rates. Details of the engineering data are provided in the remainder of this subsection.

4.3.1 Cost of Labor and Material -- CLAM(k)

Aircraft noise abatement costs (non-recurring) are aggregated into this data element. Those aircraft which are not noise abatable but are included in the model, have the labor and material costs set to zero. Baseline cost data estimates for aircraft modifications have been obtained from the airframe and engine manufacturers, Boeing (12), McDonnell-Douglas (13), and Pratt and Whitney (14), respectively. The manufacturers

and airlines (15) have also provided information concerning choices between noise abatement modification options -- such as no modification versus modification or complete re-engining. The noise abatement modification options selected for this analysis are shown in Table 4-1.

It should be noted that the use of cost data requires the application of some judgement. In particular, the re-engining of DC-8-60 series aircraft by United Air Lines, Delta Air Lines, and the Flying Tiger Line is far more expensive than shown in Table 4-2. Since the re-engining of these aircraft will also substantially extend their service lives, it would not be reasonable to charge the entire conversion cost (or aircraft down time) against noise abatement. The cost modification factor (two percent) employed in this analysis reflects the views of the author.

The analyst using the model has complete freedom to use hypothetical cost data or noise abatement options to investigate practical or theoretical alternatives. This freedom may be used, for example, to allocate some of the cost of aircraft replacement to noise abatement.

4.3.2 Operating Cost Change -- CO(k)

This data element represents a provision in the model to account for recurring changes in aircraft operating costs resulting from the noise abatement modification. These costs, which may be increases or decreases in the aggregate, are deemed negligible for the particular data set used in this analysis.

As an illustration, the re-engining of DC-8-60s results in a 20% drop in fuel consumption, which is approximately offset by a 4000 pound increase in aircraft weight.

TABLE 4-2

DATA BASE FOR COMMERCIAL AVIATION NOISE ABATEMENT ECONOMIC ANALYSIS.

IUSE= 9 GUSE= 1 KUSE= 26 SUSE= 3 TUSE= 13
EXPENSES= 1.74718E+10
REVENUES= 1.82714E+10
SIZE= 8.00 2.00 0.
UNEC=

.20	.40	.60	.80	1.00	2.00	4.00	8.00	16.00

AC NO	CHGB	CHANGE	ELB	EL	ELSTD	CO	RW	CT	CLAM	OP S=1	OP S=2	OP S=3	IGROUP	
1	83.	9.	108.5	102.9	102.9	0.	1.	10000.	224768.	741.	371.	420.	1	2
2	49.	0.	111.7	104.9	102.9	0.	1.	10000.	224768.	395.	197.	222.	1	2
3	0.	3.	0.	104.9	102.9	0.	1.	10000.	0.	24.	12.	14.	0	0
4	303.	57.	110.1	104.2	104.2	0.	1.	10000.	83224.	1205.	447.	230.	1	3
5	107.	0.	111.0	102.6	104.2	0.	1.	10000.	83224.	265.	90.	54.	1	3
6	31.	237.	109.5	103.2	104.4	0.	1.	10000.	199140.	663.	227.	134.	1	3
7	133.	0.	109.5	103.2	104.4	0.	1.	10000.	132449.	329.	112.	67.	1	3
8	76.	0.	116.0	102.9	105.6	0.	20.	10000.	2678000.	1264.	342.	19.	0	0
9	146.	0.	118.5	106.2	106.3	0.	20.	10000.	2678000.	561.	90.	7.	0	0
10	13.	0.	115.5	102.5	105.3	0.	20.	10000.	2678000.	1475.	429.	61.	0	0
11	19.	0.	114.4	108.0	108.0	0.	1.	10000.	399400.	120.	9.	1.	0	0
12	72.	0.	112.3	107.4	108.0	0.	1.	10000.	399400.	455.	33.	3.	0	0
13	19.	0.	112.5	107.4	108.0	0.	1.	10000.	399400.	199.	31.	0.	0	0
14	81.	0.	98.0	94.4	94.4	0.	1.	10000.	272576.	1481.	765.	650.	1	2
15	249.	0.	105.0	99.0	103.2	0.	1.	10000.	272576.	1518.	847.	651.	1	2
16	0.	40.	98.1	0.	96.5	0.	0.	10000.	0.	971.	607.	291.	0	0
17	0.	101.	105.4	0.	107.3	0.	0.	10000.	0.	1003.	87.	2.	0	0
18	0.	4.	108.0	0.	107.8	0.	0.	10000.	0.	978.	14.	0.	0	0
19	0.	22.	105.4	0.	107.5	0.	0.	10000.	0.	1256.	183.	31.	0	0
20	19.	0.	113.0	102.3	102.3	0.	16.	10000.	1370000.	1398.	405.	176.	0	0
21	50.	0.	110.0	103.4	103.4	0.	16.	10000.	1370000.	611.	140.	44.	0	0
22	46.	0.	110.0	100.0	103.6	0.	38.	5000.	200000.	1064.	196.	108.	0	0
23	20.	0.	112.0	100.0	104.2	0.	38.	5000.	200000.	549.	73.	6.	0	0
24	17.	0.	112.0	100.0	104.1	0.	38.	5000.	200000.	508.	65.	35.	0	0
25	0.	4.	102.4	102.4	106.0	0.	0.	0.	0.	1600.	0.	0.	0	0
26	0.	86.	102.4	102.4	107.1	0.	0.	0.	0.	1032.	246.	3.	0	0
27	0.	0.	119.5	119.5	105.2	0.	0.	0.	0.	0.	0.	0.	0	0

4.3.3 Aircraft Downtime Cost -- CT(k)

Having aircraft out of service represents a loss to its operator. This data element provides for accounting for the costs incurred while aircraft are being noise abated. CT represents the downtime unit cost, per day, week, or any time period selected by the analyst.

The specific CT(k) values in the data set used here are approximations made by the author, based on aircraft fleet sizes and revenues. The unit of time is one day.

4.3.4 Rework Downtime -- RW(k)

The length of time required for aircraft noise abatement modification is symbolized by this data element. The only restriction is that RW should agree dimensionally with CT, the unit downtime cost. The units of time need not be related to the modeling time periods.

The comments concerning labor and material costs also apply to downtime cost and duration. When benefits in addition to noise abatement are realized, only a reasonable fraction (approximately 50 percent) of the total downtime cost should be apportioned to noise abatement activities.

Rework downtime data were obtained from (12,13).

4.3.5 Noise Emission Level, Terminal -- EL(k)

EL(k) represents the noise emission level of noise abated aircraft, or of those aircraft for which no noise abatement is contemplated -- that is, all aircraft specified by the CHANGE data element (see 4.4.2).

Any noise emission measure may be used, subject to the restraint that EL, ELB (4.3.6), and ELSTD (4.4.3) employ the same

units. Noise emission levels used in this analysis are in EPNdB (effective perceived noise decibels). Noise emission data for specific aircraft were obtained from (12, 13, 16, 17).

4.3.6 Noise Emission Level, Initial -- ELB(k)

ELB(k) represents the noise emission level of aircraft prior to abatement modification -- that is, all aircraft which are specified by the CHGB data element (see 4.4.1).

All comments made in Section 4.3.5, above, are applicable.

4.3.7 Rework Upper Bound -- RWUB(k,t)

The upper limit of aircraft noise abatement modification by aircraft type and by simulation time period. The limit is due to the industrial capacity for aircraft modification. The data used in this analysis (Table 4-3) from (12, 13, 15) is made consistent with the modeling period, which is in years. It was assumed that capital investments would not be made to increase the industrial capacity for aircraft modification.

4.3.8 Rework Group Bound -- RWGB(g,t)

The upper limit of aircraft noise abatement modification by shared resource type, and by simulation time period. An aircraft modification element which is common to several aircraft types and which is of limited availability is a shared resource.

The shared resource in this analysis is the Pratt & Whitney BG-16/BG-19 "Hush Kit", used on the JT8D engines of B727, B737, and DC-9 aircraft. Specific data (Table 4-3) were obtained from (14). Note that material and facilities may both create cases of resource contention.

TABLE 4-3
INFLATION SERIES AND INDUSTRIAL CAPACITY DATA

YEAR/CINF/RWGB:

1	2	3	4	5	6	7	8	9	10	11	12	13
1.0000	1.0550	1.1130	1.1742	1.2388	1.3070	1.3788	1.4547	1.5347	1.6191	1.7081	1.8021	[illegible]
0	720	960	960	960	960	960	960	960	960	960	960	[illegible]

RWUB:

AC\YR	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	60	120	120	120	120	120	120	120	120	120	120	[illegible]
2	0	60	120	120	120	120	120	120	120	120	120	120	[illegible]
3	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
4	0	60	120	120	120	120	120	120	120	120	120	120	[illegible]
5	0	60	120	120	120	120	120	120	120	120	120	120	[illegible]
6	0	76	456	456	456	456	456	456	456	456	456	456	[illegible]
7	0	60	120	120	120	120	120	120	120	120	120	120	[illegible]
8	0	0	0	110	264	264	264	264	264	264	264	264	[illegible]
9	0	0	0	110	264	264	264	264	264	264	264	264	[illegible]
10	0	0	0	110	264	264	264	264	264	264	264	264	[illegible]
11	0	18	36	36	36	36	36	36	36	36	36	36	[illegible]
12	0	18	36	36	36	36	36	36	36	36	36	36	[illegible]
13	0	18	36	36	36	36	36	36	36	36	36	36	[illegible]
14	0	30	180	180	180	180	180	180	180	180	180	180	[illegible]
15	0	30	180	180	130	180	180	180	180	180	180	180	[illegible]
16	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
17	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
18	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
19	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
20	0	180	180	180	180	180	180	180	180	180	180	180	[illegible]
21	0	180	180	180	180	180	180	180	180	180	180	180	[illegible]
22	0	15	15	15	15	15	15	15	15	15	15	15	[illegible]
23	0	15	15	15	15	15	15	15	15	15	15	15	[illegible]
24	0	15	15	15	15	15	15	15	15	15	15	15	[illegible]
25	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
26	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]

4.3.9 Rework Group Bound Indicator -- IGROUP(g+1,k)

The presence of a rework group bound on any aircraft type is specified by a group number assigned to IGROUP(1,k). When IGROUP(1,k) is set to zero, it implies that aircraft type k is not in a resource contention situation. If IGROUP(1,k) is set to a value n, then aircraft type k is in resource contention with all other aircraft types for which IGROUP(1,i) is also set to the value n. This is illustrated in Table 4-2, where aircraft types 1, 2, 4-7, and 14, 15 are in a resource contention group.

The value of IGROUP (n+1,k) shows the quantity of the common resource required to modify aircraft type k. This is again illustrated in Table 4-2. The IGROUP value is two for B737 and DC-9 aircraft (k:1,2,14,15), and is set to three for the B727 aircraft (k:4-7).

4.4 NOISE ABATEMENT ENVIRONMENTAL DATA

Operating environment data provide fleet size and utilization information, noise emission standards, inflation, airport size, and unit surcharge data, which are discussed in the remainder of this section.

4.4.1 Noise Abatable Fleet Size -- CHGB(k,t)

The value of CHGB(k,1) specifies the number of unabated but abatable aircraft of type k, at the time of model initiation. The value of CHGB(k,i), ($i \neq 1$) specifies the introduction to or retirement from the initial fleet, depending on whether the value is positive or negative. These data, shown in Table 4-2, were obtained from (18,19). The carriers which are included in the analysis are shown in Table 4-4.

4.4.2 Noise Abated Fleet Size -- CHANGE(k,t)

The value of CHANGE(k,1) specifies the number of noise abated, or unabatable aircraft, of type k, at the time of model

TABLE 4-4

Carriers included in NAEPAM Development

Airlift International, Inc.
Air Midwest
Air New England, Inc.
Alaska Airlines, Inc.
Allegheny Airlines, Inc.
Aloha Airlines, Inc.
American Airlines, Inc.
Aspen Airways, Inc.
Braniff Airways, Inc.
Continental Air Lines, Inc.
Delta Air Lines, Inc.
Eastern Air Lines, Inc.
Flying Tiger Line Inc., The
Frontier Airlines, Inc.
Hawaiian Airlines, Inc.
Hughes Air Corp. dba Hughes Airwest
National Airlines, Inc.
North Central Airlines, Inc.
Northwest Airlines, Inc.
Ozark Air Lines, Inc.
Pan American World Airways, Inc.
Piedmont Aviation, Inc.
Seaboard World Airlines, Inc.
Southern Airways, Inc.
Texas International Airlines, Inc.
Trans World Airlines, Inc.
United Air Lines, Inc.
Western Air Lines, Inc.
Wien Air Alaska, Inc.
Wright Air Lines, Inc.

initiation. The use of this array is completely analogous to the CHGB array.

4.4.3 Noise Emission Level Standard -- ELSTD(k)

The noise emission level, by aircraft type, at (or below) which no noise emission charge is assessed. For the purpose of this analysis, the FAR-36 (4) standards are used, in worst-case form (Table 4-2). The worst-case form arises from the standards being established for the take-off, cutback, sideline, and approach measuring points. For a selected aircraft, let the standard at each measuring point be denoted by ELSTD(j), then the worst-case is determined by that measuring point which yields:

$$\max_{j} \left(ELB(j) - ELSTD(j) \right) \tag{4.1}$$

Then, let j' be the value of j at which the maximum occurs. The excess noise emission level is then determined by:

$$\max\left(\left(ELB(j') - ELSTD(j') \right), 0 \right) \tag{4.2}$$

Eq. 4.2 states that aircraft which emit noise below the standard will not be subject to negative penalties -- or benefits. The only requirement for noise measurement is that actual emission levels and the standards be dimensionally consistent.

Noise emission level standards may be either real or hypothetical, and may also use complex measures which relate excess noise to other performance measures, such as EPNdB per pound of installed thrust, EPNdB per pound of gross weight, EPNdB per ton of payload, EPNdB per ton-mile, etc.

4.4.4 Airport Noise Sensitivity Coefficient -- SIZE(s)

The airport size class coefficient is used in the development of the system of noise emission charges as a surrogate

for airport noise sensitivity. In this analysis, the coefficients are used as simple multipliers. Alternate formulations, using functions in place of coefficients, are feasible. The size classification used in this analysis is the standard air traffic hub rule of large, medium, and small hubs (see footnote 1 on page 1-3). Non-hubs were not used in the analysis. The specific coefficient values of 8:2:1 were obtained from the enplanement ratios at large, medium, and small hubs, using the Airport Activity Statistics (10). The sensitivity of the model to this coefficient will be demonstrated in Section 5, where the model is evaluated with coefficients valued at 20, 4, and 1.

4.4.5 Aircraft Utilization -- OP(k,t,s)

Aircraft utilization is specified as average operations per aircraft for each aircraft type (k), by each modeling time period (t), by each airport size class (s). Utilization data, shown on Table 4-2, are obtained from the Aviation Activity Statistics (AAS) (10) and from fleet size information, Sections 4.4.1 and 4.4.2. The AAS is available in data base form at The Computer Company (TCC), (20). Table 4-5 illustrates one page of AAS output, as provided by TCC, showing operations aggregated within hub size class, by aircraft type, by carrier. Hub size classification was taken from Tables 3, 4, and 5 of the AAS. These data, aggregated across all carriers within hub size class, by aircraft type, divided by fleet size provide the average aircraft utilization.

Note that two assumptions concerning utilization were made in the present analysis. First, it is assumed that during the 12-month sampling period, the aircraft in question were optimally utilized, and that this optimal utilization rate would be used as long as the aircraft remain in service. Second, air traffic growth requirements during the modeling period would be satisfied by aircraft in compliance with the noise emission level standards (ELSTD, Section 4.3.3) used in the model.

TABLE 4-5

SAMPLE OF OPERATING DATA

SMALL HUB CITY TRAFFIC
SCHEDULED PLUS NON-SCHEDULED SERVICE
FOR THE YEAR ENDING JUNE 30TH, 1977

NITED AIR LINES		DEPARTURES PERFORMED	TOTAL PAX ENPLANED	TOTAL MAIL/ TONS ENPLANED	TOTAL EXPRESS PLUS FREIGHT/ TONS ENPLANED
			4,508,387	7,662	14,929
620	B-737-200 BOEING TURBO-FAN	34,979			
621	B-737-200C BOEING TURBO-FAN				
630	DC-9-10 DOUGLAS TURBO-FAN				
635	DC-9-15F DOUGLAS TURBO-FAN				
640	DC-9-30 DOUGLAS TURBO-FAN				
650	DC-9-50 DOUGLAS				
690	A-300B AIRBUS				
710	B-727-100 BOEING TURBO-FAN	35,486			
711	B-727-100C/QC BOEING TURBO-FAN				
715	B-727-200 BOEING TURBO-FAN	13,421			
730	DC-10-10 DOUGLAS TURBO-FAN	189			
731	DC-10-20 DOUGLAS TURBO-FAN				
732	DC-10-30 DOUGLAS TURBO-FAN				
733	DC-10-40 DOUGLAS TURBO-FAN				
760	L-1011 LOCKHEED TURBO-FAN				
800	B-707-100 BOEING				
802	B-707-100B BOEING TURBO-FAN				
804	B-707-200 BOEING				
806	B-707-300 BOEING				
808	B-707-300B BOEING TURBO-FAN				
809	B-707-300C BOEING TURBO-FAN				
812	B-720-000 BOEING				
814	B-720-000B BOEING TURBO-FAN				
816	B-747 BOEING TURBO-FAN				
818	B-747C BOEING TURBO-FAN				
820	B-747F BOEING TURBO-FAN				
822	B-747SP BOEING				
840	DC-8-10 DOUGLAS				
842	DC-8-20 DOUGLAS	3,463			
844	DC-8-30 DOUGLAS				
845	DC-8-62 DOUGLAS				
848	DC-8-50 DOUGLAS	1,456			
850	DC-8-50F DOUGLAS TURBO-FAN	15			
851	DC-8-61 DOUGLAS TURBO-FAN	3,174			
852	DC-8-63F DOUGLAS TURBO-FAN				
854	DC-8-62 DOUGLAS TURBO-FAN	461			
856	DC-8-63 DOUGLAS TURBO-FAN				

Note that the above assumptions apply to this analysis only. The NAEPAM data structure is designed so that the assumptions may be altered for future use of the model.

4.4.6 Inflation Series -- CINF(t)

It is assumed that both noise emission charges and noise abatement modification costs would be subject to the effects of inflation. Accordingly, the optimizations were performed using a constant annual inflation rate of 5.5 percent, based on considerations in (21).

The effect of inflation may be completely eliminated from the model by setting all values of CINF to unity. Alternately, the analyst may insert any desired (constant rate or variable) inflation series.

4.4.7 Unit Noise Emission Charge -- UNEC(i)

The unit noise emission charge notion is fundamental to the system of charge developed through this model. This unit charge is the amount of charge made at a small hub for each excess EPNdB if noise is above the standard specified for each aircraft. The system of charges is then derived using these equations:

$$NECHGB(k,t,s) = (ELB(k)-ELSTD(k)) * CINF(t) * SIZE(S) * UNEC(i) \quad (4.3)$$
$$NECHG(k,t,s) = (EL(k)-ELSTD(k)) * CINF(t) * SIZE(S) * UNEC(i) \quad (4.4)$$

where, by definition:

$$EL-ELSTD \geq 0, \; ELB-ELSTD \geq 0 \quad \text{for all } k \quad (4.5)$$

The reason for subscripting UNEC is to facilitate model execution. That is, several UNEC values can be input for optimization in a single set of computer runs, with minimal activity by the analyst.

Note that the large (or medium) hub class may be chosen as the basis for the UNEC, with a suitable change to the SIZE coefficient value. More significantly, the excess noise measure (EL-ELSTD) may be replaced by different formulations, which take into account the psychological effects of increasing noise levels. One such formulation is proposed (in a somewhat different context) by Cell & Morrall (8).

SECTION 5. RESULTS AND DISCUSSION

5.1 SYSTEM OF NOISE EMISSION CHARGES

A sample tariff of charges for excess noise emission is illustrated by Table 5-1. For administrative ease, a table of this type could be indexed by aircraft make/model/serial number and noise abatement status. Such tables can be provided both in printed and computer readable form. The significance of the illustrated tariff will be discussed in the following section, where the consequences of the tariffs are described.

5.2 CHARGE SYSTEM EVALUATION

The effects of a NEC system are assessed by comparison with other NEC systems analyzed under the same scenario, as well as other scenarios. A scenario represents a set of assumptions made about the noise abatement engineering options, about the operating environment, and about the set responses available to the carrier industry to counter the NEC system. An analysis set consists of a single scenario, under which several UNECs are analyzed. An analysis set under a single scenario is often referred to as a "study", which is identified by a letter designation.

Figure 5-1 shows the residual noise emission level time histories for Study B, the baseline scenario. The horizontal axis is in years, while the vertical axis is in millions of excess EPNdBs, that is, noise emissions above the standard, accumulated on an annual basis as a simple sum. Each line is labelled with the value of the corresponding UNEC. The graph shows that both terminal year residual noise level, and the rate of noise abatement modifications are a function of the UNECs. The curves are non-increasing since it is assumed that aviation growth will be satisfied by adding new aircraft to the fleet which are in compliance with noise emission standards.

TABLE 5-1

SAMPLE TARIFF FOR EXCESS NOISE EMISSION

AC NO	LARGE HUB ABATED	LARGE HUB UNAB.	MEDIUM HUB ABATED	MEDIUM HUB UNAB.	SMALL HUB ABATED	SMALL HUB UNAB.	AIRCRAFT MAKE/MODEL	ENGINE	NOISE ABATEM
1	0.	26.88	0.	6.72	0.	3.36	B737-200	JT8D-7	FCD+
2	9.60	42.24	2.40	10.56	1.20	5.28	B737-200/200C	JT8D-9	FCD+
3	9.60	0.	2.40	0.	1.20	0.	B737-200	JT8D-15,-17	FCD+
4	0.	28.32	0.	7.08	0.	3.54	B727-100C/QC	JT8D-7	FCD+
5	0.	32.64	0.	8.16	0.	4.08	B727-200	JT8D-7	FCD+
6	0.	24.48	0.	6.12	0.	3.06	B727-200	JT8D-9	FCD+
7	0.	24.48	0.	6.12	0.	3.06	B727-200	JT8D-15,-17	FCD+
8	0.	49.92	0.	12.48	0.	6.24	B707-100B	JT3D-1,-3,-3B	QN
9	0.	58.56	0.	14.64	0.	7.32	B707-300B/C	JT3D,JT4A	QN
10	0.	48.96	0.	12.24	0.	6.12	B720B	JT3D	QN
11	0.	30.72	0.	7.68	0.	3.84	B747-100	JT9D-3A	SAM
12	0.	20.64	0.	5.16	0.	2.58	B747-100	JT9D-7	SAM
13	0.	21.60	0.	5.40	0.	2.70	B747-200B/C/F/SP	JT9D-7	SAM
14	0.	17.28	0.	4.32	0.	2.16	DC-9-10	JT8D-5,-1	FCD+
15	0.	8.64	0.	2.16	0.	1.08	DC-9-30	JT8D-9,-15,-17	FCD+
16	0.	7.68	0.	1.92	0.	.96	DC-9-50	JT8D-15,-17	
17	0.	0.	0.	0.	0.	0.	DC-10-10	CF6-6D1	
18	0.	.96	0.	.24	0.	.12	DC-10-30	CF6-50C	
19	0.	0.	0.	0.	0.	0.	DC-10-40	JT9D-20	
20	0.	51.36	0.	12.84	0.	6.42	DC-8-20	JT3D	SAM
21	0.	31.68	0.	7.92	0.	3.96	DC-8-50	JT3D-3B	SAM
22	0.	30.72	0.	7.68	0.	3.84	DC-8-61	JT3D	CFM-
23	0.	37.44	0.	9.36	0.	4.68	DC-8-63F	JT3D	CFM-
24	0.	37.92	0.	9.48	0.	4.74	DC-8-62	JT3D	CFM-
25	0.	0.	0.	0.	0.	0.	A-300B	CF6-50	
26	0.	0.	0.	0.	0.	0.	L-1011-200	RB.211-524	
27	68.64	68.64	17.16	17.16	8.58	8.58	CONCORDE	OLYMPUS 593/MK 610	

UNIT NOISE EMISSION CHARGE = .60 $/EXCESS EPNDB

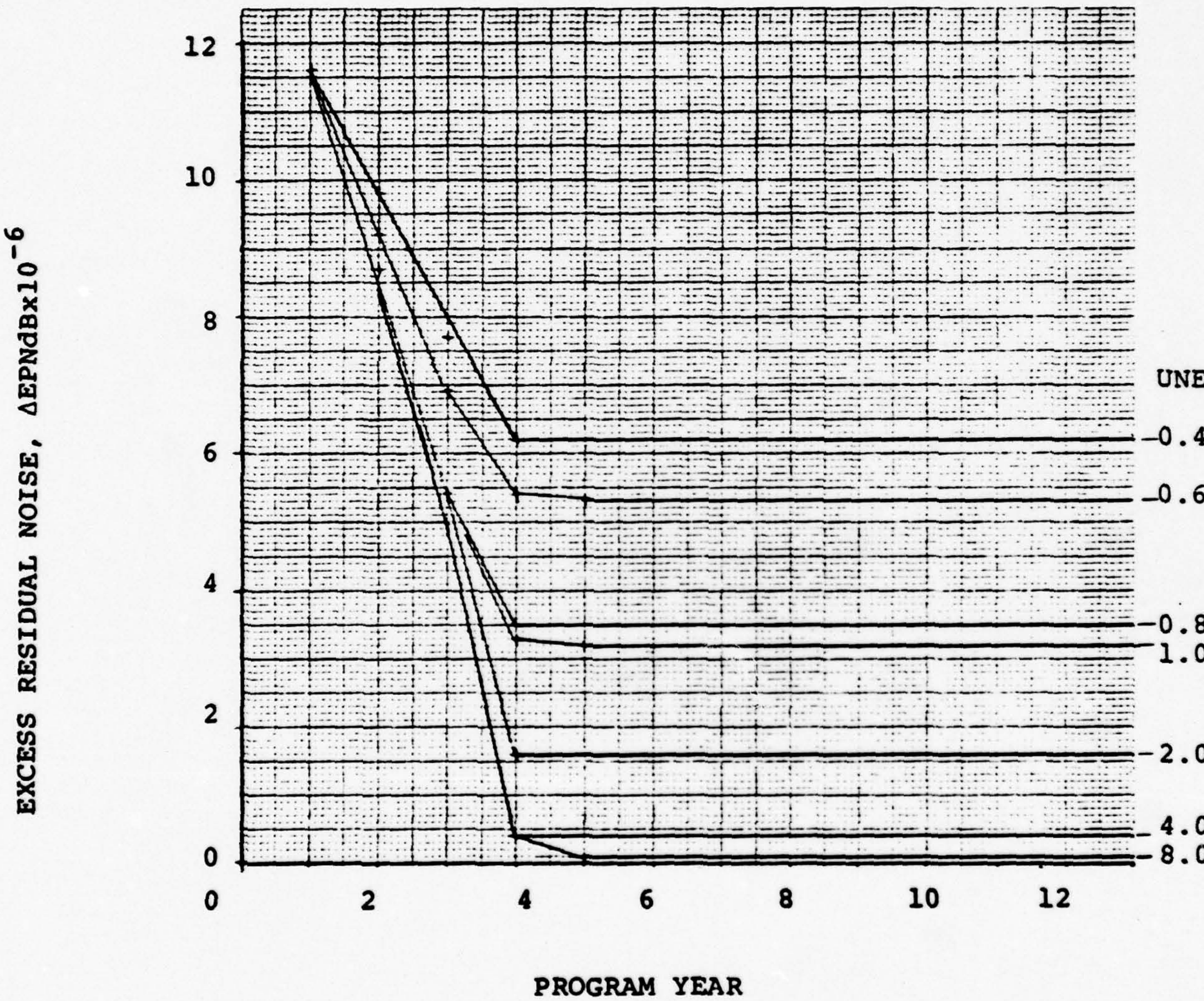

FIGURE 5-1. RESIDUAL NOISE PROFILE AS A FUNCTION OF UNIT NOISE EMISSION CHARGES AND TIME

The excess residual noise as a function of total program cost is shown in Figure 5-2 for the baseline scenario. The curve is annotated with the UNEC values that produce each point. It is clear that as UNEC increases from 0.2 to 8$/ΔEPNdB the excess residual noise diminishes, while the total program cost increases. Note that at UNEC greater than 8$/ΔEPNdB the program cost increases without any further gains in residual noise reduction.

Section 5.3 describes the post-optimization analysis which produces the results shown on Figures 5-1 and 5-2. Results obtained under various scenarios are compared in Section 5.4. The implications of the model are discussed in Section 5.5.

5.3 POST-OPTIMIZATION ANALYSIS

The objective of the model described in Section 3 is to determine the aircraft noise abatement modification schedule which minimizes total program cost. As noted earlier, the total program cost is the sum of aircraft modification costs and noise emission charges paid for unabated operations.

The optimization results are illustrated by Table 5-2 for a particular scenario (J), and for a specific value of UNEC (2$/ΔEPNdB). The table shows an optimal schedule, as well as totals by year of program and aircraft type. The 1298 aircraft to be abated under this result represent 85 percent of the abatable[1/] aircraft considered in the analysis.

The consequences of compliance with the optimal solution are obtained during the post-optimization analysis. The result of the post-optimization analysis (POA) is illustrated by Table 5-3. The POA employs the same data set as the optimization.

[1/] The sum of the CHGB data element in Table 4-2 (1533). There are also 563 abated or unabatable aircraft included.

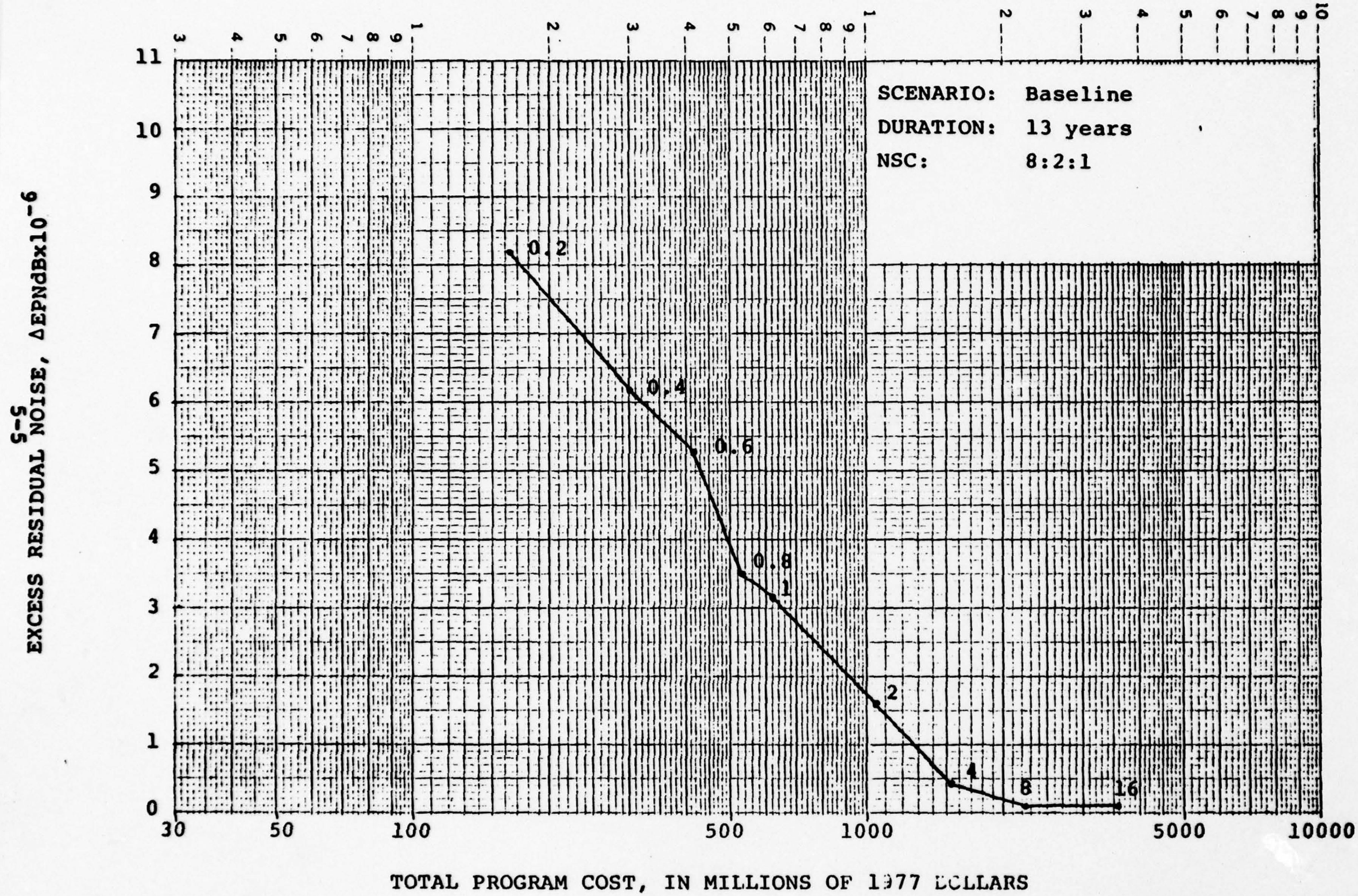

FIGURE 5-2. EXCESS RESIDUAL NOISE AS A FUNCTION OF PROGRAM COST

TABLE 5-2

PROBLEM MOD V6 J - SOLUTION NUMBER 6 - OPTIMAL
UNIT NOISE EMISSION CHARGE = 2.00 $/EXCESS EPNDB

THE TABLE BELOW IS THE NOISE ABATEMENT MODIFICATION SCHEDULE WHICH IS COST OPTIMIZED.

AC\YR	1	2	3	4	5	6	7	8	9	10	11	12	13	TOT
1	0	60	23	0	0	0	0	0	0	0	0	0	0	83
2	0	49	0	0	0	0	0	0	0	0	0	0	0	49
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	60	120	120	3	0	0	0	0	0	0	0	0	303
5	0	0	0	107	0	0	0	0	0	0	0	0	0	107
6	0	31	0	0	0	0	0	0	0	0	0	0	0	31
7	0	36	30	66	0	0	0	0	0	0	0	0	0	132
8	0	0	0	76	0	0	0	0	0	0	0	0	0	76
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	13	0	0	0	0	0	0	0	0	0	13
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	18	36	18	0	0	0	0	0	0	0	0	0	72
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	30	51	0	0	0	0	0	0	0	0	0	0	81
15	0	30	180	39	0	0	0	0	0	0	0	0	0	249
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	19	0	0	0	0	0	0	0	0	0	0	0	19
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	15	15	15	1	0	0	0	0	0	0	0	0	46
23	0	15	5	0	0	0	0	0	0	0	0	0	0	20
24	0	15	2	0	0	0	0	0	0	0	0	0	0	17
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOT	0	378	462	454	4	0	0	0	0	0	0	0	0	1298

TABLE 5-3

POST-OPTIMIZATION ANALYSIS
COMMERCIAL AVIATION NOISE ABATEMENT ECONOMICS STUDY

1 PROBLEM MOD V6 J - SOLUTION NUMBER 6 - OPTIMAL
CREATED ON JUNE 26TH, 1979 13:55:48 , AFTER 45 ITERATIONS
TOTAL INFLTD COST, M$ 1243.04

2 UNIT NOISE EMISSION CHARGE = 2.00 $/EXCESS EPNDB

3 BASE O.R. = 95.62

	NOISE EMISSION CHARGE:M$				AC MOD	TOTAL	EXCESS EPNDB		$MOD/	$MOD %	TOT COST (F) AS % OF			CHANGED
YR	MAX	UNABATED	ABATED	UNAB+AB	COST	COSTS	RESIDUAL	SAVING	$NECHGS	TOTAL	FARES	OP EXP	GR INC	OP RAT
	A	B	C	D=B+C	E	F=D+E	G	H	I=E/D	J=E/F%	K	L	M	N
1	132.1	132.1	.0	132.1	0.	132.1	11.6	0.	0.	0.	.723	.756	16.52	96.35
	132.1	132.1	.0	132.1	0.	132.1	11.6	0.	0.	0.	.723	.756	16.52	96.35
2	132.1	100.6	.7	101.3	113.7	215.1	8.7	2.9	1.12	52.99	1.177	1.231	26.90	96.90
	264.2	232.8	.7	233.5	113.7	347.2	20.3	2.9	.49	32.76	.950	.994	21.71	96.57
3	132.1	65.9	.7	66.6	109.5	176.1	5.3	6.3	1.64	62.17	.964	1.008	22.02	96.59
	396.4	299.7	1.4	300.1	223.2	523.3	25.6	9.2	.74	42.65	.955	.998	21.91	96.59
4	132.1	21.1	.7	21.8	310.9	332.7	1.6	10.0	14.28	93.45	1.821	1.904	41.61	97.44
	528.5	319.7	2.1	321.8	534.1	856.0	27.2	19.1	1.66	62.40	1.171	1.225	26.75	96.79
5	132.1	20.6	.7	21.3	.7	22.0	1.6	10.0	.03	3.05	.120	.126	2.75	95.74
	660.6	340.3	2.8	343.1	534.8	877.9	28.7	29.2	1.56	60.92	.951	1.005	21.96	96.58
6	132.1	20.6	.7	21.3	0.	21.3	1.6	10.0	0.	0.	.117	.122	2.66	95.74
	792.7	360.9	3.5	364.4	534.8	899.2	30.3	39.2	1.47	59.47	.820	.858	18.74	96.44
7	132.1	20.6	.7	21.3	0.	21.3	1.6	10.0	0.	0.	.117	.122	2.66	95.74
	924.8	381.5	4.2	385.7	534.8	920.5	31.8	49.2	1.39	58.10	.720	.753	16.45	96.34
8	132.1	20.6	.7	21.3	0.	21.3	1.6	10.0	0.	0.	.117	.122	2.66	95.74
	1057.0	402.1	4.9	407.0	534.8	941.8	33.4	59.3	1.31	56.78	.644	.674	14.72	96.27
9	132.1	20.6	.7	21.3	0.	21.3	1.6	10.0	0.	0.	.117	.122	2.66	95.74
	1189.1	422.7	5.6	428.3	534.8	963.1	34.9	69.3	1.25	55.53	.596	.612	13.38	96.21
10	132.1	20.6	.7	21.3	0.	21.3	1.6	10.0	0.	0.	.117	.122	2.66	95.74
	1321.2	443.3	6.3	449.6	534.8	984.4	36.5	79.3	1.19	54.33	.539	.563	12.31	96.16
11	132.1	20.6	.7	21.3	0.	21.3	1.6	10.0	0.	0.	.117	.122	2.66	95.74
	1453.3	463.9	7.0	470.9	534.8	1005.7	38.0	89.3	1.14	53.18	.500	.523	11.43	96.12
12	132.1	20.6	.7	21.3	0.	21.3	1.6	10.0	0.	0.	.117	.122	2.66	95.74
	1585.4	484.5	7.7	492.2	534.8	1027.0	39.6	99.4	1.09	52.08	.468	.490	10.70	96.09
13	132.1	20.6	.7	21.3	0.	21.3	1.6	10.0	0.	0.	.117	.122	2.66	95.74
	1717.6	505.1	8.4	513.5	534.8	1048.3	41.1	109.4	1.04	51.02	.441	.462	10.09	96.07

NOTES: A) ALL COSTS (COLUMNS A-F) ARE IN MILLIONS OF 1977 DOLLARS.
B) COLUMNS G-H ARE IN MILLIONS OF EPNDB.
C) COLUMN I IS A PURE RATIO.
D) COLUMNS J-N ARE PERCENTAGES.

The only additional inputs to it are the optimization results, which are shown in Table 5-2. The POA results are described in detail on the following pages.

The block of three lines, labelled "1", are taken from the optimization output. The first of the three lines shows the model version designation, V6, the study designation, scenario J, the solution number, which is used in managing the optimization solution file, and the word "optimal" indicating that an optimal solution was found. The second line shows the date and time stamp at which the optimization was performed, as well as the number of iterations required to reach this optimal solution. The third line shows the total program cost, in inflated dollars, since the optimization is performed with both aircraft modification costs and NECs subject to inflation.

Item 2 indicates the specific UNEC value at which these results are obtained. Item 3 will be discussed later in the section, in conjunction with column N.

The body of the table shows the various values calculated by year. The first of each line pair, labelled with the year of the program, is the current year's value, while the unlabelled line is the cumulative value of each column respectively. It is important to note that the POA is performed in constant year dollars, in contrast to the optimization which employs inflated dollars. Using constant year dollars in the POA facilitates the comparison of various scenarios.

The first column of the table indicates the year for which data in that line are presented.

<u>Column A</u> is the value of the NECs which would be paid if no noise abatement modifications were performed.

The remainder of the columns, B-N, are computed under the assumption that the optimal solution is implemented.

Column B is the value of the NECs paid for operations with unabated, but abatable, aircraft, in millions of dollars. Note that this value decreases markedly each year as noise abatement modifications are performed.

Column C is the value of the NECs paid for operations with abated, or unabatable, aircraft, in millions of dollars.

Column D is the total NECs paid for operations on both abated and unabated aircraft, in millions of dollars.

Column E shows the cost of aircraft noise abatement modifications, in millions of dollars.

Column F is the total program cost, including NECs and aircraft modification costs, in millions of dollars.

Column G is the sum of the residual noise (above the standard) at large, medium, and small hubs, in millions of EPNdBs. Note that excess noise is defined as:

$$\max\ ((EL-ELSTD),\ 0) \qquad (5.1)$$

$$\max\ ((ELB-ELSTD),\ 0) \qquad (5.2)$$

indicating that no "credits" are given for exceeding the requirements. Further note that, while the NECs are weighted by the airport size coefficient, the residual noise values are not weighted.

Under the assumption stated earlier that air traffic growth requirements will be satisfied by aircraft in compliance with the noise emission standards, the first year value of column G represents the maximum residual noise.

Column H represents the savings in residual noise due to aircraft noise abatement modifications, in millions of EPNdBs. The value in column H for year n is the difference between column G, year one and column G, year n.

Column I is the ratio of aircraft modification costs (column E) and total NECs (column D).

Column J is the aircraft modification cost expressed as a percentage of the total program cost.

Column K is the total program cost (column F) expressed as a percentage of passenger and freight revenues. The underlying assumptions are that all of the program costs will be passed through to passengers and shippers by the carrier industry, thus raising fares, and that the industry will not experience any real growth of revenues during the modeling period. Other assumptions may be substituted by the analyst to replace the above, probably conservative, set.

The revenue basis for this calculation, shown in Table 4-2, is obtained from (22). Observe that the cumulative values in column K are optimistic to the extent that the cost of capital is not included in the total program cost. The error bound to this optimism is provided by the yearly values of column K, which represent a pay-as-you-go approach.

Column L is the total program cost (column F) expressed as a percentage of airline operating expenses, under the assumption that the entire cost will be absorbed by the carrier industry. All other discussions under column K apply to these data as well.

Column M is the total program cost (column F) expressed as a percentage of the carriers' gross income. The gross income is the difference between revenues and operating expenses.

Column N reflects the carrier industry's operating ratio (operating expenses divided by operating revenues) under the assumption that the total program cost is absorbed by the industry as an increase of the operating expenses. The operating ratio prior to the introduction of the NECs is shown as item 3 of Table 5-3.

5.4 RESULTS

The behavior of a system of noise emission charges was illustrated for a specific scenario in Figure 5-2. The behavior of the model is demonstrated by the comparison of various scenarios, which are summarized in Table 5-4. This section is devoted to showing the model's behavior through six comparative studies which examine the effects of program duration, industrial capacity changes, aircraft retirement, airport size coefficient variation, and alteration of the noise emission standard. The effects of the participation level by airports in assessing NECs is also examined in this section.

5.4.1 Program Duration Effect

The scenario selected as baseline for the series of analyses is a 13-year program, with airport size (noise sensitivity) coefficients of 8:2:1 for large, medium, and small hubs, respectively. The baseline response set of the carrier industry is to modify aircraft according to the optimal schedule provided by the optimization model.

To assess the impact of program duration, the baseline scenario (Study B) is compared with an eight-year program (Study C), as shown on Figure 5-3. Comparison of the two scenarios at any program cost shows that lower residual noise level is achieved by the 13-year program. Alternatively, comparing the two curves at any residual noise level shows that it can be achieved at a lower cost by the 13-year program. As can be expected, at any total program cost value, the 13-year program achieves the lower residual noise level at a lower UNEC value. Since these observations are

TABLE 5-4
SUMMARY OF ANALYSIS SCENARIOS

STUDY DESIGNATION	A	B	C	D	E	F	G	H	I	J
DURATION, YEARS	13	13	8	8	13	13	13	13	13	13
NSC 1/	8:2:1	8:2:1	8:2:1	20:4:1	8:2:1	8:2:1	0:2:0	8:0:0	0:0:1	8:2:0
INDUSTRIAL CAPACITY	LOW	NORMAL	←						→	NORMAL
NOISE ABATEMENT COST	HIGH	NORMAL	←						→	NORMAL
AIRCRAFT RETIREMENT	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
NOISE EMISSION STD 2/	N	N	N	N	N	S	N	N	N	N

NOTES:

1/ Noise sensitivity coefficients, Large : Medium : Small Hubs

2/ N: Normal -- FAR-36
S: Stringent

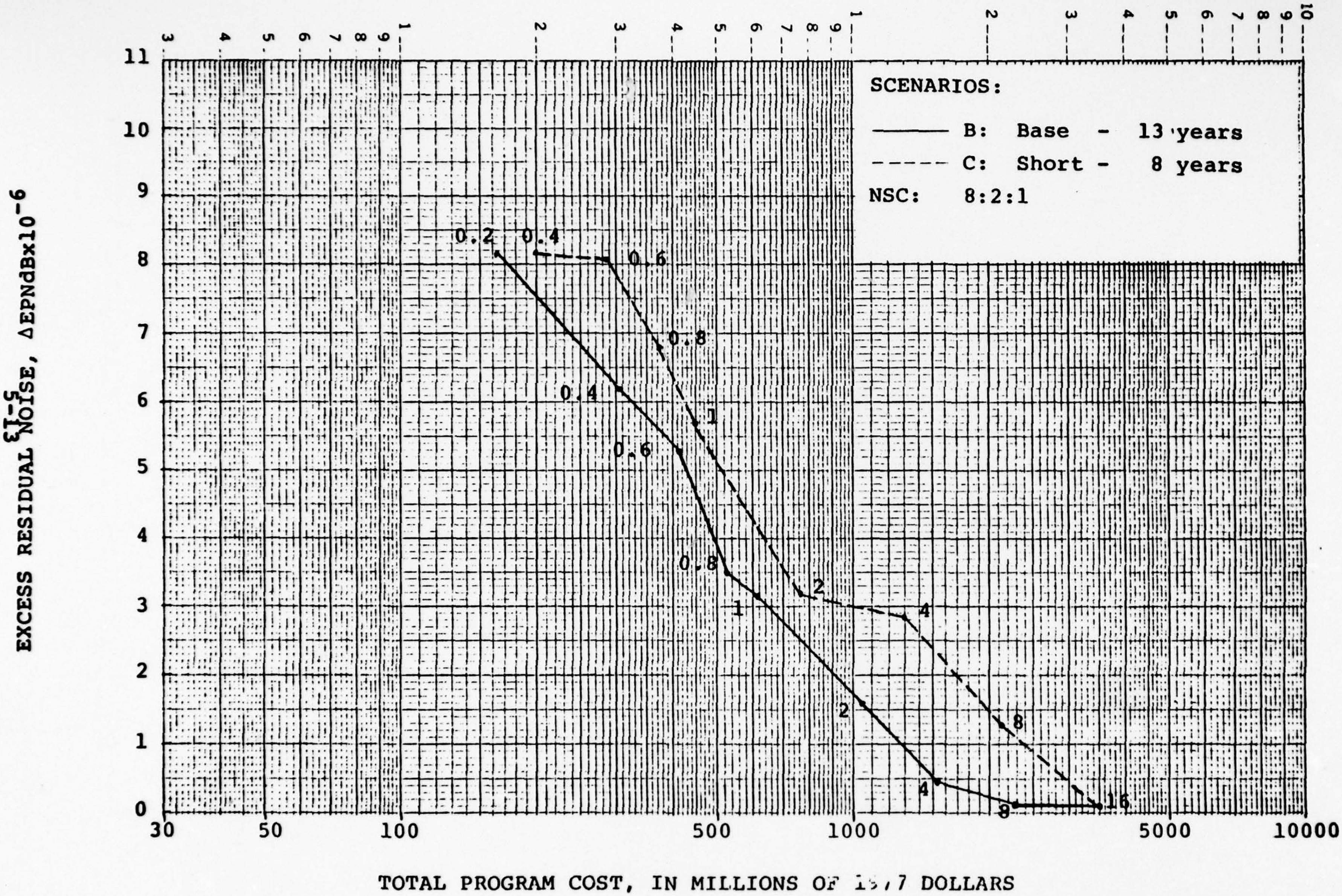

FIGURE 5-3. EFFECT OF PROGRAM DURATION

true at all points of the comparison, it is obvious that the 13-year program dominates the eight-year program.

The components of the total program cost: aircraft modifications and NECs are shown on Figure 5-4. The result of the comparison satisfies the intuition that noise abatement modification costs are nearly identical at all residual noise levels, and that higher total program cost for the eight-year program is due almost entirely to the NECs.

Comparison of the eight and 13 year programs at identical UNEC values (on Figures 5-3 and 5-4) shows that the 13-year program results in better performance than the eight year program. This effect is due to the higher prospective NECs that would be accrued with increasing program duration.

5.4.2 Industrial Capacity and Modification Cost Effect

This analysis compares the baseline scenario (Study B) with Study A where some of the aircraft modification conditions are more stringent. Specifically, the maximum modification rate for DC-8-20s and DC-8-50s is lower in Study A than it is in B. Simultaneously, the modification cost for the DC-8-60 series is higher in Study A than it is in Study B. These two differences involve a total of 152 aircraft (9.9%) out of the 1533 abatable aircraft included in the analysis. Figure 5-5 shows the comparison of the two studies. Scenario B clearly dominates scenario A which has the relatively adverse modification condition. The difference between the two scenarios, with only a small fraction of the fleet involved, indicates considerable model sensitivity to noise abatement modification parameters.

This model sensitivity could be utilized to explore noise abatement research and development economics by evaluating the cost effectiveness of potential results. It may also be used

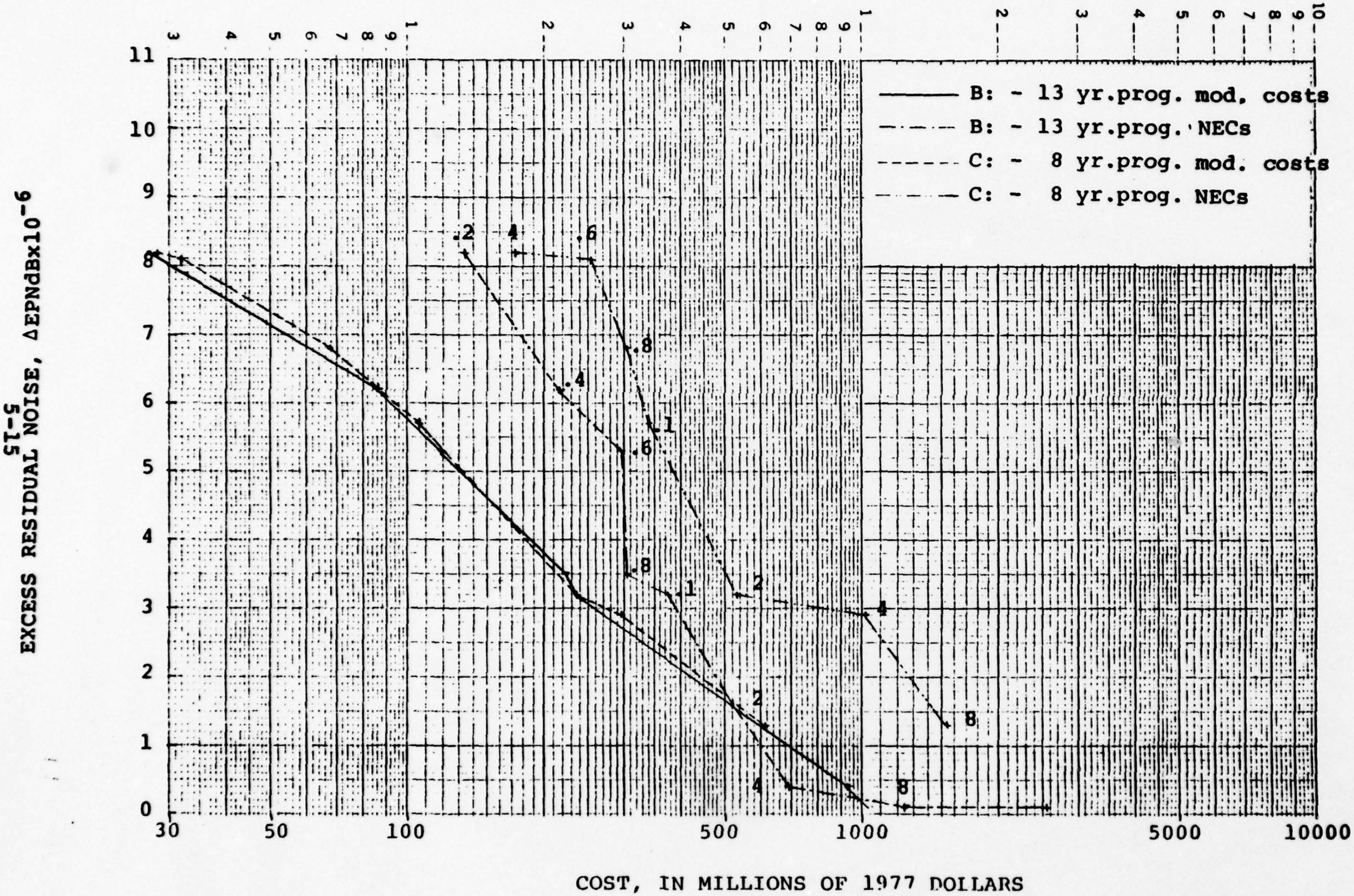

FIGURE 5-4. EFFECT OF PROGRAM DURATION ON MODIFICATION COSTS AND NOISE EMISSION CHARGES

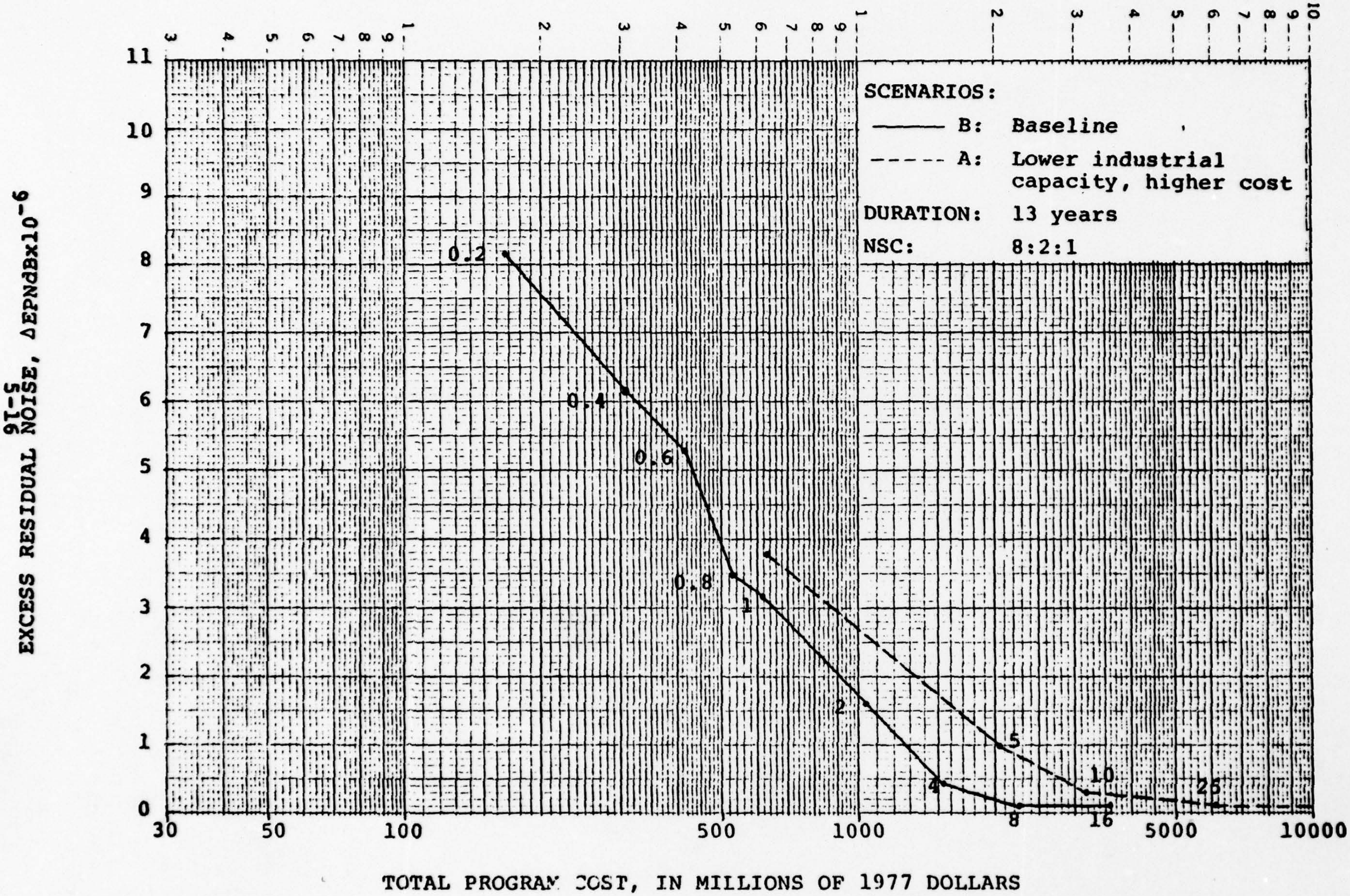

FIGURE 5-5. EFFECT OF CHANGES IN INDUSTRIAL CAPACITY AND MODIFICATION COSTS

for social policy analysis, by evaluating the effects of changing noise abatement costs through trust fund, tax incentive, cost-sharing or other financial arrangements.

5.4.3 Aircraft Retirement Effect

The high cost of aircraft noise abatement modification, and the age of early jet aircraft motivated the examination of aircraft retirement as an alternative to modification. (Aircraft age data are shown in Appendix C of Reference 1.) A hypothetical retirement scenario was constructed after the examination of alternatives considered in the Environmental Impact Statement, Appendix B (17). Under this scenario, 69 percent of the B707/B720 (235 total) fleet is retired during the second and third year of the program, along with 25 percent of the DC-8-20s and -50s (69 total) during the second program year. These retirements represent 11.7 percent of the 1533 abatable aircraft included in the analysis.

The two scenarios are compared graphically on Figure 5-6. It is evident that Study E, with the retirements, substantially dominates Study B, the baseline, which allows no retirement. It is important to note that this relationship is observed under the (potentially critical) assumption that none of the costs associated with aircraft retirement and replacement are allocated to noise abatement. The sensitivity of the model in this respect would enable the exploration of alternative scenarios, which might reflect some tax advantages for early retirement of aircraft for noise abatement reasons. Such tax advantages could be provided, for example, through depreciation or capital loss mechanisms.

5.4.4 Noise Sensitivity Coefficient Effect

In the baseline scenario, the enplanement ratio between large, medium, and small hubs is used as a surrogate measure of noise sensitivity. An alternative ratio set, selected by the author, is used to test the model's sensitivity. The eight-year program was used to compare the baseline (8:2:1) coefficients against the alternative (20:4:1). The comparison, shown on Figure 5-7, indicates that between 430 and 900 million dollars total

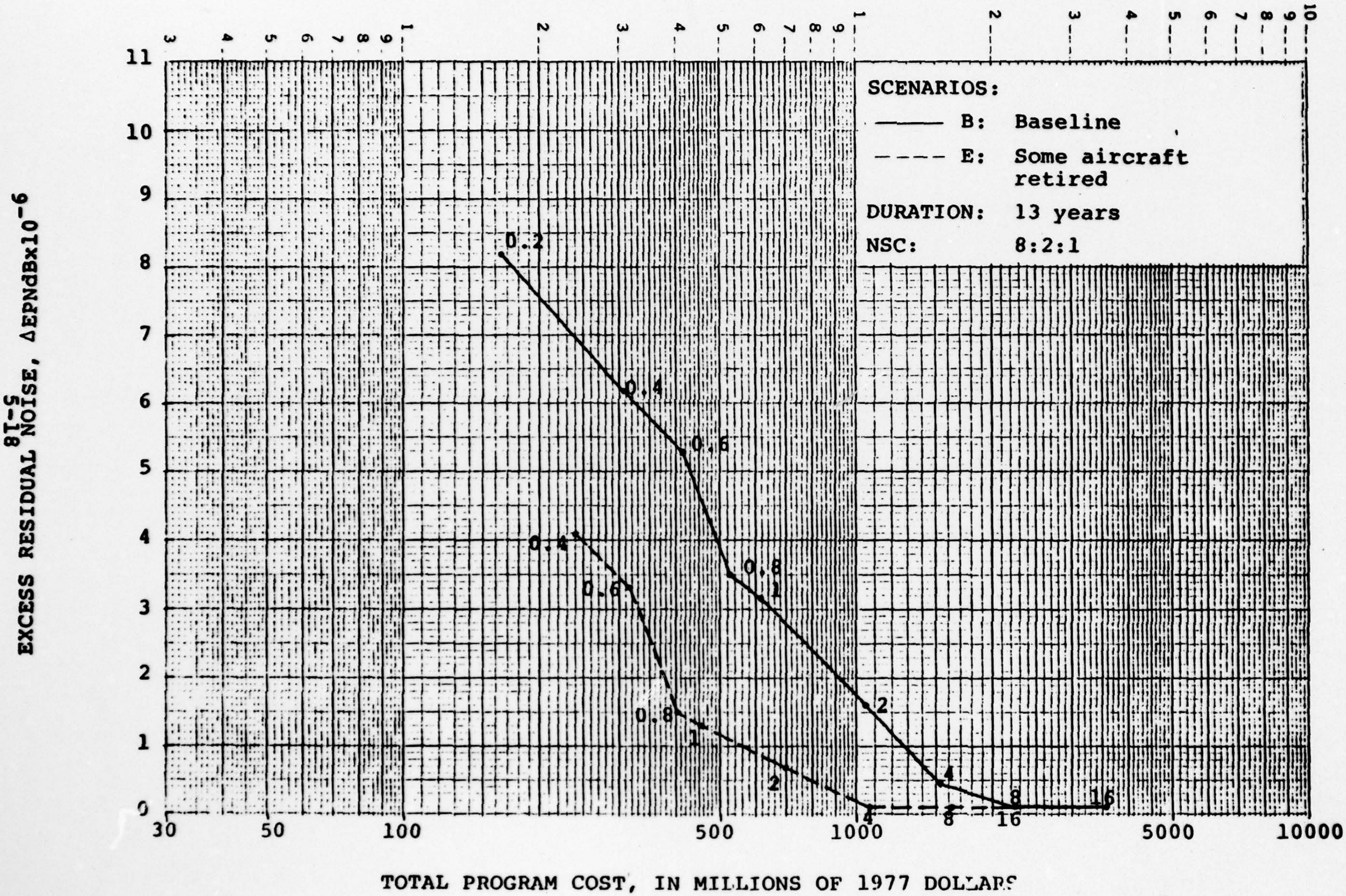

FIGURE 5-6. EFFECT OF AIRCRAFT RETIREMENT VS. NOISE ABATEMENT MODIFICATION

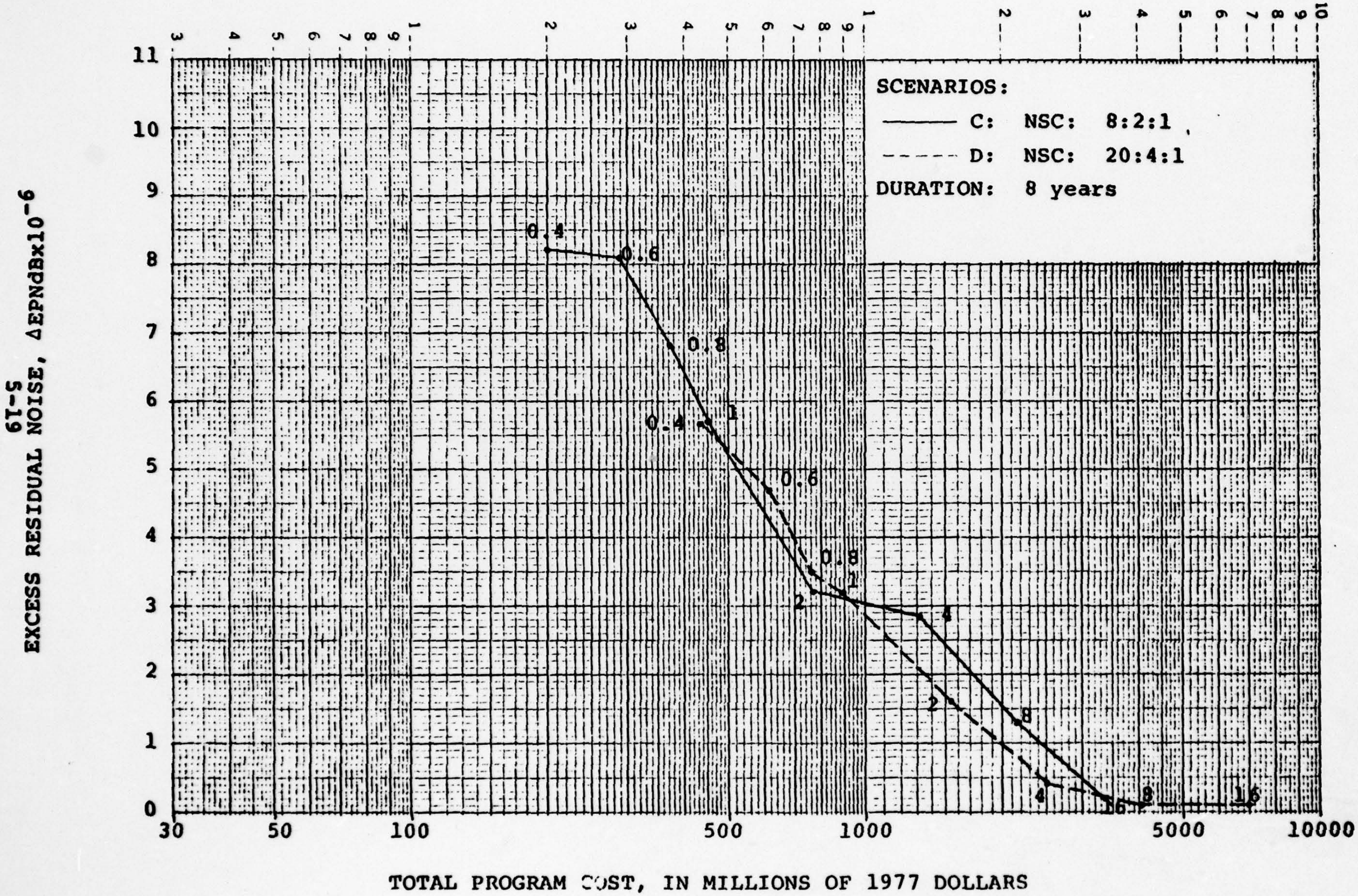

FIGURE 5-7. COMPARISON OF EFFECT OF NOISE SENSITIVITY COEFFICIENTS

program cost, scenario C (lower coefficient values) dominates, while above 900 M$ the programs are reversed. These data are inconclusive, indicating the need for further exploration of the effects of the noise sensitivity coefficients.

The complexity of the modeled behavior is displayed with the aid of the data on Table 5-5. The table summarizes the post optimization analyses for Studies C and D. Intuition is satisfied by the results since the decreasing residual noise values are perfectly negatively rank-order correlated with the unit noise emission charge values, modification costs, and noise emission charges. The two scenarios are virtually identical at the 5.7 million EPNdB Residual Noise Level (RNL) which occurs at UNECs of 0.4 and 1.0, respectively. Note that at this point, the ratio of the UNECs is identical to the ratio of large-hub noise sensitivity coefficients of 20 and 8, respectively. At the 3.2 RNL, the abatement modification costs are identical. The noise emission charges required to motivate the modification level are, however, substantially different -- 529 and 648 M$, respectively. The opposite of this phenomenon can be observed at the 2.9 - 1.6 RNL and the 1.3 - 0.4 RNL, respectively. In these cases, virtually identical noise emission charges result in substantially different noise abatement modification expenditures, which result in different RNLs.

Further investigation of this phenomenon may result in the development of scenarios where the modification cost to noise emission charge ratio is controlled by the analyst.

The noise sensitivity coefficient concept, as used in this model, may be replaced by alternative notions. As an example, the noise emission charge could be related to the market forces of various hubs. These forces could be measured as a fraction of GNP generated at the hubs, SMSA level economic indices or any of a large number of other possibilities.

5.4.5 Noise Emission Standard Alteration Effect

The sensitivity of the model to changes in the noise emission standard was examined in Study F. Study F differs from the baseline by a one EPNdB drop in the noise emission standard

TABLE 5-5

Details of Model Behavior

RESIDUAL NOISE	UNEC		AIRCRAFT MODIFICATION COST		NOISE EMISSION CHARGES	
	8:2:1	20:4:1	8:2:1	20:4:1	8:2:1	20:4:1
8.2	0.4	-	28.2	-	171.4	-
8.1	0.6	-	32.0	-	253.5	-
6.8	0.8	-	67.7	-	303.2	-
5.7	1	0.4	106.1	105.8	339.5	331.5
4.7	-	0.6	-	162.5	-	444.1
3.5	-	0.8	-	226.5	-	528.3
3.2	2	1	237.6	237.6	529.0	648.3
2.9	4	-	297.1	-	1002	-
1.6	-	2	-	523.2	-	1009
1.3	8	-	614.9	-	1540	-
0.4	-	4	-	931.9	-	1572

for all aircraft types. Figure 5-8 shows that the two scenarios behave very similarly, with the less stringent standard dominating. Note that this effect is shown with identical noise abatement technology, which is currently 'calibrated' for the FAR-36 noise emission standards. The effects of change could vary substantially with a different type of noise measurement and standard, such as NEF based measurement, or an aircraft productivity based set of standards.

5.4.6 Participation Level Effect

The baseline results of the NAEPA model are predicated on having all large, medium, and small hub class airports assess the noise emission charge system. This subsection examines the effects of selective participation in the program.

The marginal impact of participation by the collection of small hubs can be observed in Figure 5-9, which shows the baseline and Study J, where only the large and medium hubs are assumed to participate. At low UNEC levels, up to 1.0 $/ΔEPNdB, the all-hubs program slightly dominates the large-medium hub combination. At the higher UNEC levels, the two programs are essentially identical.

Another view of small hub participation is given in Figure 5-10. While the small-hubs-only scenario appears to dominate the baseline case, the corresponding UNEC levels indicate a lack of realism. Unit noise emission charges of 8$/ΔEPNdB or above, at small hubs, appear to be tenuous.

A number of similar comparisons can be made, which indicate similar conclusions. Comparing Studies I and G (Figure 5-11), small-hubs-only vs. medium-hubs-only, shows that identical results, in terms of residual noise, are attained at identical total program cost. The requisite for achieving the results shown with limited participation is high levels of UNEC, since the small hubs alone lack the economic leverage to present an adequate economic disincentive.

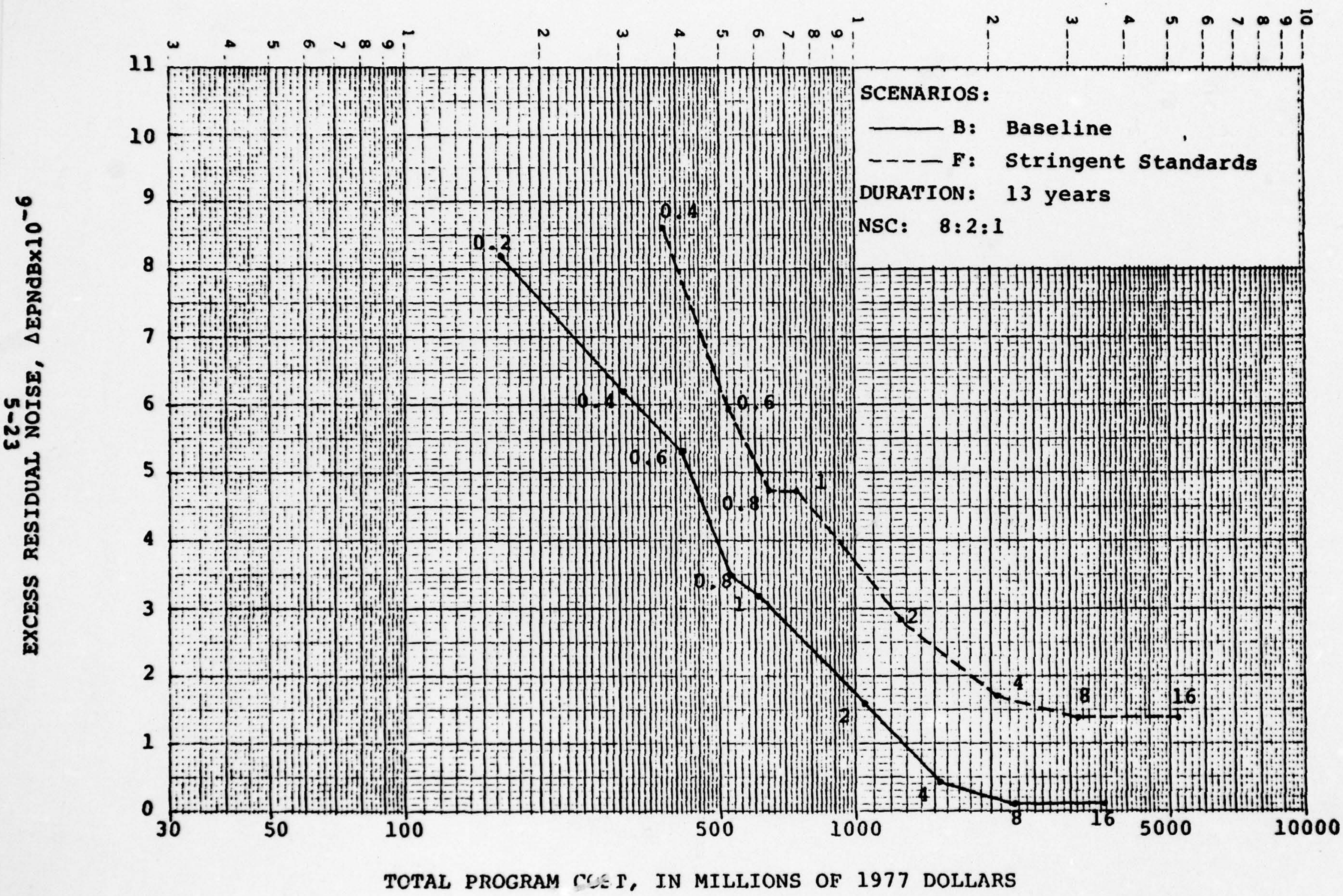

FIGURE 5-8. COMPARISON OF EFFECT OF NOISE EMISSION LEVEL STANDARDS

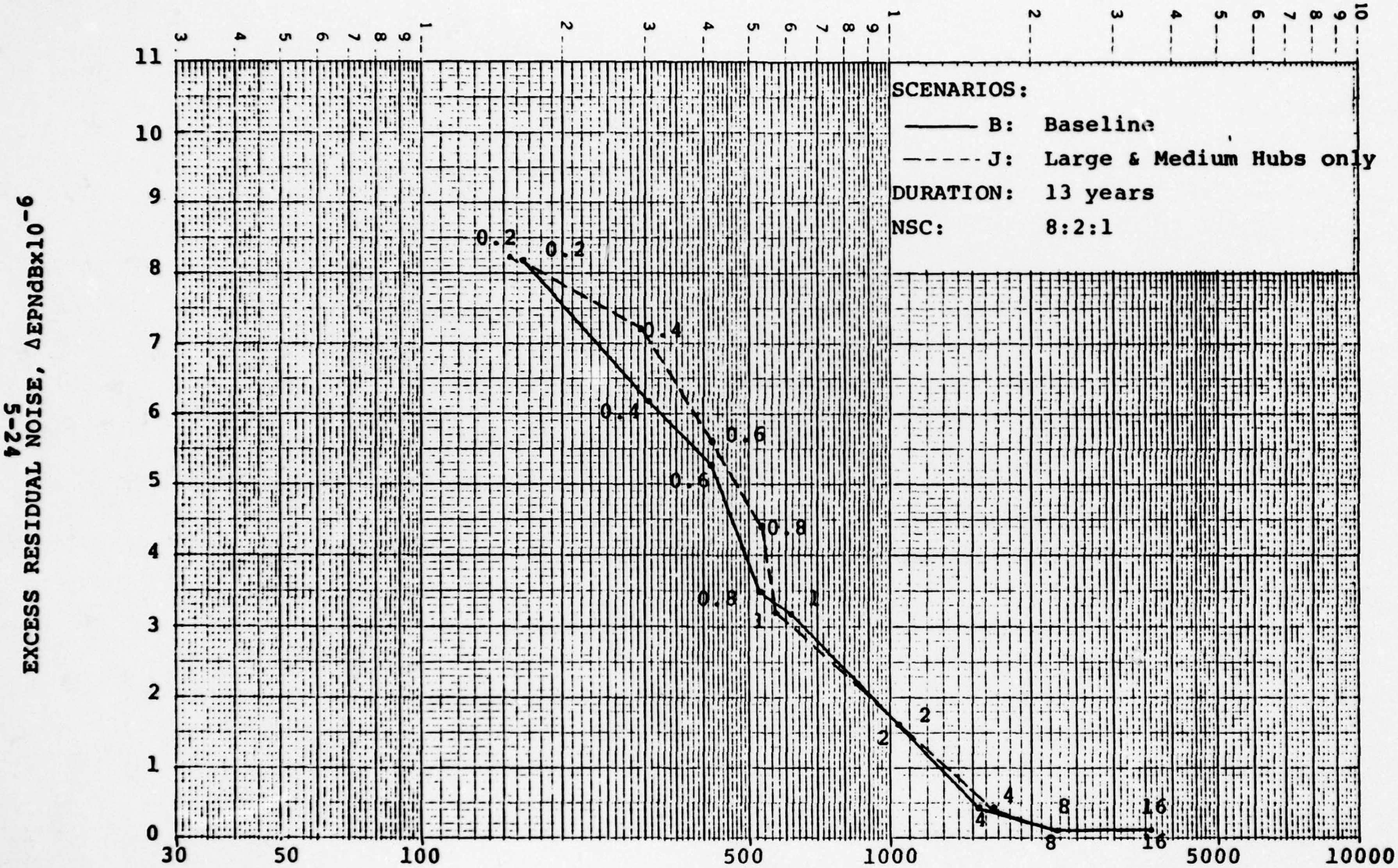

FIGURE 5-9. PARTICIPATION LEVEL EFFECT--BASELINE VS. LARGE & MEDIUM HUBS ONLY

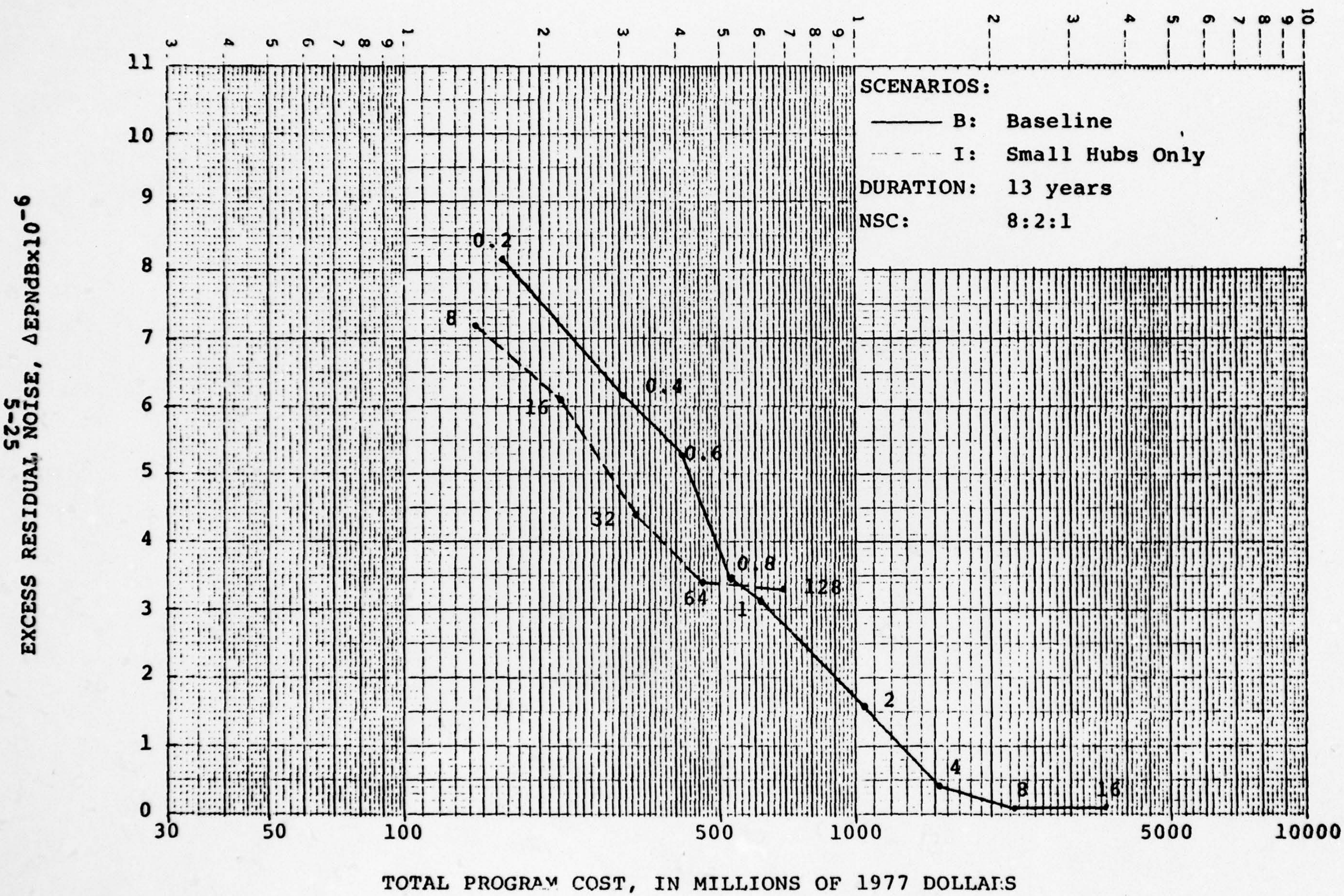

FIGURE 5-10. PARTICIPATION LEVEL EFFECT--BASELINE VS. SMALL HUBS ONLY

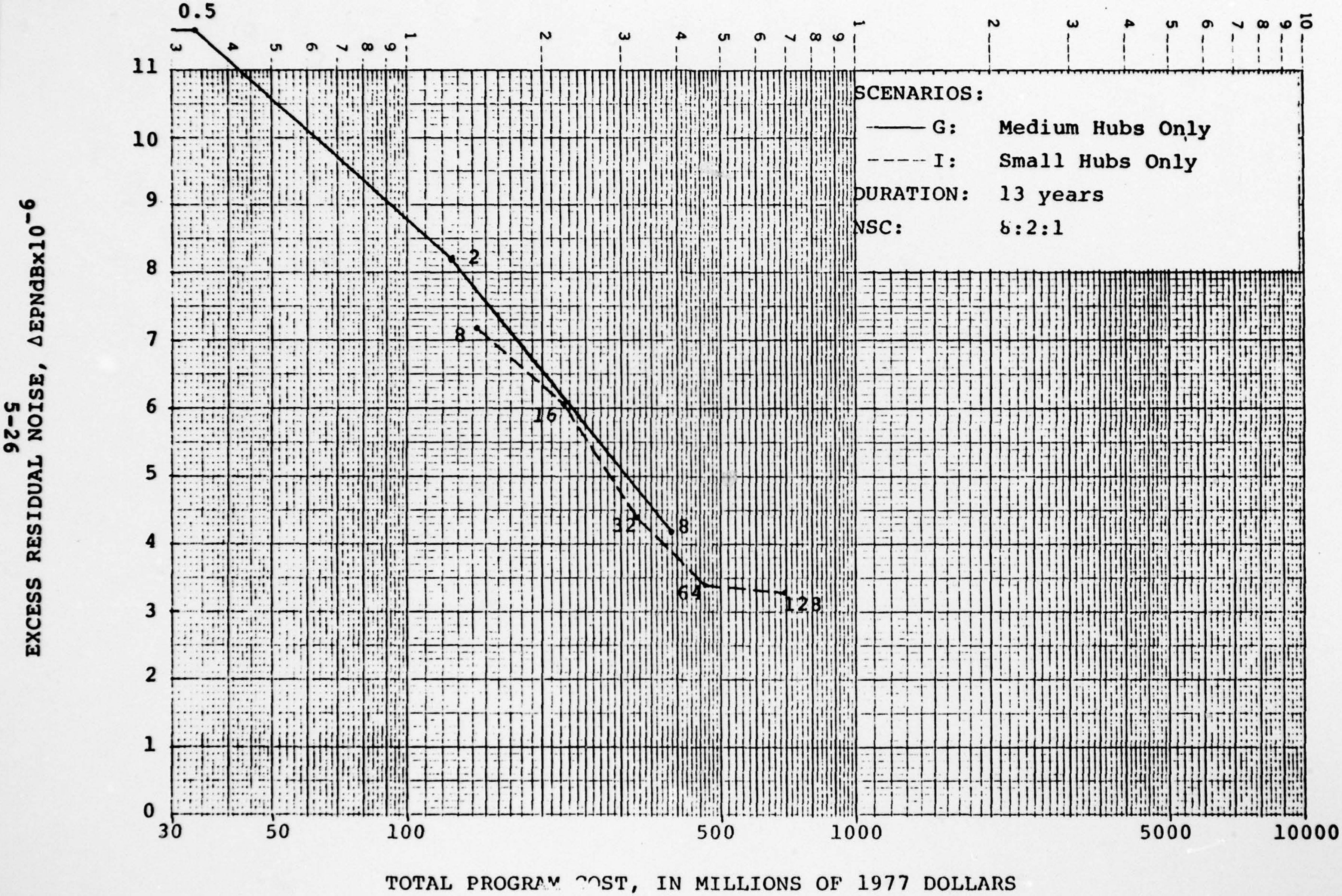

FIGURE 5-11. PARTICIPATION LEVEL EFFECT--MEDIUM VS. SMALL HUBS ONLY

5.5 DISCUSSION

5.5.1 Noise Emission Charge System Selection

Sufficient data have been presented in Section 5.4 to indicate that there is a breadth of choices available for noise emission charge system selection. It is clear from the data shown that an inherent "best charge" does not exist. The selection of a system of charges requires the definition of objectives and constraints. Some of the objectives may, in fact, be effectiveness measures. The simplest objectives are to "reduce annual residual noise to X EPNdB" or "the total program cost shall not exceed Y dollars." The expectation of such simply stated objectives is probably idealistic in the economically, technologically and institutionally complex aviation environment.

The issues which will require some degree of resolution in the objective selection process include: what is a suitable measure of noise[1/], what is the appropriate noise emission standard, will the charge system be mandatory or optional, which airports will participate in the program, how will the program be financed? The NAEPA model presented in this document cannot provide the answers to these questions; it can, however, provide the analytical support for exploring the issues necessary for policy development.

5.5.2 Airport Participation Level in Program

Section 5.4.6 demonstrated, under the set of assumptions in this analysis, that a substantial level of airport participation is necessary to obtain the economic leverage for this approach to noise abatement. Put another way, this approach is not suitable for establishing noise emission charge systems for use by individual airports in an uncoordinated manner, if the objective of the program is source noise abatement.

[1/] Candidates include, but are not limited to, the basic measures of dB, dBA, PNdB, EPNdB, as well as cumulative measures L_{dn}, NEF, WECPNL, etc.

To obtain noise relief in the absence of a broad scope program, the alternatives are service curtailment or noise receiver relief. Noise receiver relief programs are examined by references (7, 8). It appears that on a national scale, noise receiver relief is far more costly than noise source abatement. Nevertheless, the model presented here can be modified to rationally apportion the cost of relief for any selected locality. Since the data exist to calculate the cost of noise receiver relief at individual airports, a carefully-designed analysis could conclusively compare the costs and benefits of the two approaches to noise abatement. The comparison would require that the two approaches be based on identical assumptions, noise measurement techniques, etc. The analytical methods now, however, exist to perform such an analysis.

5.6 CONCLUSIONS

The NAEPA model presented in this document:

1) Demonstrates, under a set of assumptions, that the method of noise emission charges imposed at airports on aircraft operations violating noise emission standards is an economically feasible method for inducing noise abatement modification of aircraft.

2) Demonstrates a methodology for noise emission charge development and evaluation, and

3) Provides a framework and the necessary constructs for further analyses in noise abatement economic policy development.

The issues which may be investigated using this model include, but are not limited to:

1) Resource generation for noise receiver relief,

2) Relief to carriers for noise abatement,

3) Analysis of noise abatement R&D investment policies,

4) Consequences of alternative noise pollution standards,

5) Time of day pricing,

6) Impact of sub-optimal aircraft replacement policies, and

7) Alternative noise abatement technology economics.

The scope of the model can, if necessary, be expanded to increase the range of explorable issues.

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